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RECORDS

OF

STEAM BOILER EXPLOSIONS,

BY

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1869.

PREFACE.

ACCURATE information as to Boiler Explosions must always be useful to those who are interested in the safe working of Steam Boilers.

The following pages contain very brief abstracts of records obtained for the Midland Steam Boiler Inspection and Assurance Company, by whose permission they are now republished in a compact and convenient form.

By permission of the Council of the Institution of Mechanical Engineers, the records are prefaced by a paper on Steam Boiler Explosions and their records, and on Inspection as a means of prevention, read before that Institution at Manchester, August 1st, 1866.

All names of Works or Firms are omitted from the records as unnecessary.

ON STEAM BOILER EXPLOSIONS AND THEIR RECORDS, AND ON INSPECTION AS A MEANS OF PREVENTION, BY EDWARD B. MARTEN, MEM. INST. M.E. A.I.C.E., EXCERPT MINUTES OF PROCEEDINGS OF THE MEETING OF THE INSTITUTION OF MECHANICAL ENGINEERS, AT MANCHESTER, 1ST AUGUST, 1866, JOSEPH WHITWORTH, ESQ., PRESIDENT, IN THE CHAIR. BY PERMISSION OF THE COUNCIL.

THE subject of Steam Boiler Explosions, which was brought before this Institution in June, 1848, in a paper by the late Mr. William Smith of Dudley in reference to an explosion near that place, and again in 1859 in a paper by Mr. Longridge on the economy and durability of stationary boilers, is one of great importance and is now attracting increased attention. The first public notice of the subject was by a parliamentary committee in 1817, which was appointed in consequence of a very fatal boiler explosion in London in 1815; evidence was then collected as to steamboats, and many boiler explosions were referred to. That committee recommended among other things that boilers should be made of wrought iron, instead of cast iron or copper, which had been the materials mainly used previously; that they should be inspected and tested; and that there should be two safety valves, each loaded to one third of the test pressure, under penalties for any excess. A great part of the information now existing upon the subject, especially in regard to the earlier explosions, is to be found in the records of inquests after fatal cases; and some of the careful reports of eminent engineers on those occasions have materially assisted in the formation of correct views as to the causes of explosion. Latterly also the printed reports of the inspectors of mines, and more especially the reports of the explosions of locomotives, illustrated by diagrams by the inspectors of railways, have furnished very valuable information. Since the subject has been taken up by private associations for the

prevention of explosions, many more records have been published, although their usefulness is much impaired by their not containing the names of the places whereby the explosions could be identified.

When the writer's attention was first directed to this subject, he met with great difficulty in obtaining correct records of boiler explosions, from which to arrive at the results of past experience; and wishing to base his own opinion on facts, rather than on the inferences of others however reliable, he followed the example of the Franklin Institute in their elaborate investigation of the subject, and collected all the records he could find; and by way of facilitating reference, arranged an index, a manuscript copy of which is presented with the present paper to the Library of this Institution. All must be agreed as to the importance of reliable information on such accidents as boiler explosions; and the writer would suggest that this Institution may materially aid in obtaining the desired records and placing them within easy access, by becoming the depository of reports on explosions, and by inducing those who have the opportunity to forward copies of reports, that these may be arranged so as to be easily found and consulted. It is very desirable that these reports should as far as possible be illustrated by sketches, as aids to the description; and also by slight models like those now shown to the meeting, by which the whole matter may be seen at a glance. So few persons comparatively have the opportunity of examining boilers after explosion, that the most erroneous ideas have prevailed, and theories have been advanced which would soon be dissipated by practical experience or by reading accurate reports. It would also very much aid in the understanding of published matter on the subject, if full descriptions of each case alluded to in illustration could be obtained. These records are as useful to the engineer as the "precedents" or "cases" to the lawyer or the surgeon. After any serious explosion, the newspapers of the neighbourhood in which it has occurred contain voluminous articles describing the disastrous result and the damage done, which, although useful as far as they go, do not in the least assist in arriving at the cause of explosion. The really important particulars, such as the description

and construction of the boiler, its dimensions, and the pressure at which it worked, are in most cases omitted altogether.

The record of explosions presented to the Institution contains a list of the boiler explosions in each year of the present century, as far as known to the writer, with the names of the places, and the description and sizes of the boilers, and the supposed cause of explosion, together with references to the books or papers from which further information may be obtained. Of course many of the explosions have to be put down as uncertain in some of the particulars; but every year improves the record, as fresh information is obtained, and with the assistance of the members of this Institution it might be made far more perfect and extensive.

The total number of explosions here recorded is 1046, and they caused the death of 4076 persons and the injury of 2903. The causes assigned for the several explosions are very numerous, and are no doubt incorrect in many cases; but they may be generally stated as follows:

397 are too uncertain to place under any heading; but of the rest

145 were from the boilers being worn out, or from corrosion, or from deteriorated plates or rivets.

137 from over pressure, from safety valves being wedged or overweighted, in some cases intentionally, or from other acts of carelessness.

125 from faulty construction of boiler or fittings, want of stays, or neglect of timely repair.

119 from collapse of internal tubes, generally from insufficient strength.

114 from shortness of water, or from scurf preventing the proper contact of the water with the plates; or from improper setting so as to expose the sides of the boiler to the flame above the water line.

9 from extraneous causes, such as effect of lightning striking down the stacks upon the boilers, or from fire in the building or explosion of gas in the flues.

1046 total number of explosions.

ng descriptions :—

under any head ; but of

oilers internally fired.

lar boilers.

dally fired.

Butterley, British-tube,

or crane boilers.

oilers.

dling or mill furnaces at

non have been numerous.

hen the steam was used

ressure in the boiler was

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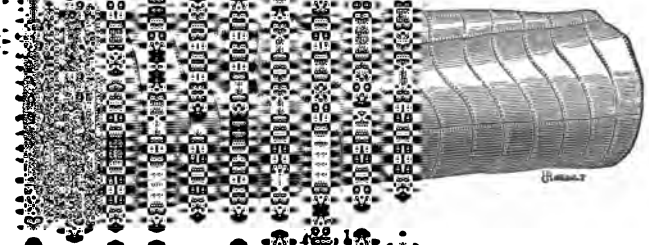
collapsed or crumpled up ;

valve still found on old

a boiler in the neighbour-

this way by collapse from

accident is shown in Fig. 1.



early explosions were so

rs, which compared with

constructed, that no one

thought of any other cause than the insufficient strength of the vessel to bear the expansive force of the steam contained in it. When the advantages of high-pressure steam became recognized, and the boilers were improved so as to bear the increased strain, the tremendous havoc caused by an explosion led many to think that something more must be required than the expansive force of the steam to produce such an effect; and they appear to have attributed to steam under certain conditions a detonating force, or a sudden access of expansive power that overcame all resistance. To support this somewhat natural supposition, it was asserted that the steam became partially decomposed into its constituent gases, forming an explosive mixture within the boiler. That this belief is still sometimes entertained is seen from the verdict of a jury even in the present year, 1866, in the case of the explosion of a plain cylindrical boiler at Leicester, shown in Fig. 2., the real

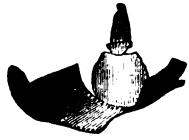


Fig. 2.

cause of which appears to have been that the shell of the boiler was weakened by the manhole. It seems hardly necessary to point out the fallacy of imagining decomposition and recomposition of the steam to take place in succession in the same vessel without the introduction of any new element for causing a change of chemical combination; but it is necessary to refer to this supposition, as the idea is shown to be not yet extinct.

Again it has been asserted that the steam when remaining quite still in the boiler becomes heated much beyond the temperature due to the pressure; and that therefore when it is stirred or mixed or brought more in contact with the water by the opening of a valve or other cause, the water evaporates so rapidly as to produce an excessive pressure by accumulation of steam. In support of this view the frequency of explosions upon the starting of the engine after a short stand is adduced; but it is very doubtful whether by this means a sufficient extra pressure could be produced to cause an explosion,

unless the boiler had been previously working up to within a very small margin of its strength. Explosions are seldom caused by a sudden increase of pressure, but rather by the pressure gradually mounting to the bursting point, when of course the effect is sudden enough. Nor is it necessary in many cases to look for much increase of pressure as the cause of explosion; for it is far more often the case that the strength of the boiler has gradually degenerated by wear or corrosion, until unable to bear even the ordinary working pressure. It is so very easy, when examining the scene of an explosion, for the first cause of rupture to be confounded with the causes of the subsequent mischief, that in many cases erroneous conclusions have been arrived at in this way.

The most important points to find out in connection with any explosion are the condition of the boiler and all belonging to it immediately before the explosion, together with the locality of the first rent, the direction of the line of rupture, and the nature of the fracture; as everything occurring after the instant of the first rent is an effect and not a cause of explosion. As soon as the first rent has taken place, the balance of strain in the fabric is disturbed, and therefore the internal pressure has greatly increased power in continuing the rupture; and also the pressure being then removed from the surface of the water, which is already heated to the temperature of the steam, the whole body of the water gives out its heat in the form of steam at a considerable pressure, and thus supplies the volume of steam for carrying on the work of destruction. When thus quickly generated, the steam perhaps carries part of the water with it in the same way that it does in ordinary priming; and it has been thought by some that the impact of the water is thus added to that of the steam, to aid in the shock given to all surrounding obstacles.

It is seldom that one out of a bed of boilers explodes without more or less injury to the others on either side of it; but sometimes two boilers in one bed, or three, or even five, have exploded simultaneously.

The causes of boiler explosions may be considered under the two general heads of—

itself as originally

ys, bad material,

and

her from wear and

ter or accumulation

of general thinning,

; or from flaws or

of repeated strain;

quate arrangements

plosions were from

now used were then

asier to work were

selected as the one

e of copper or cast

he weakest possible

shown in Fig. 3.

s. 4 and 5. The

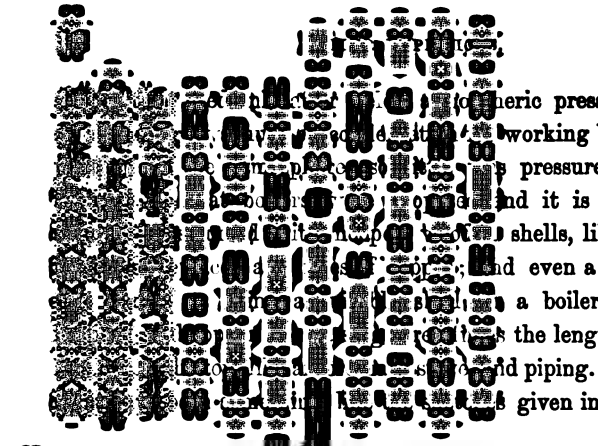
Fig. 5.

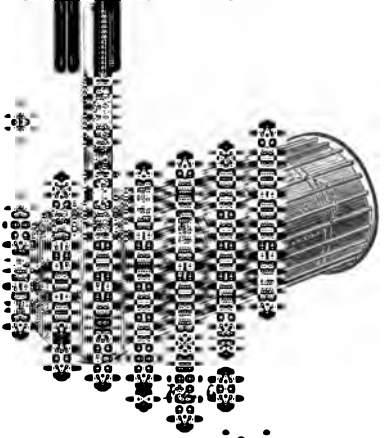
eferred to by the

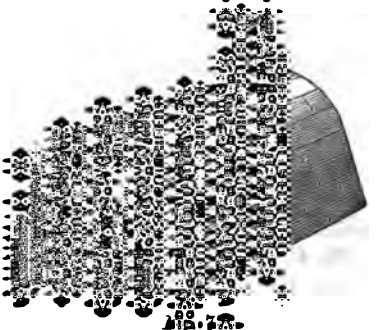
was of a cast-iron

thin to bear the

The steam being







of boilers, with an

shown in Fig. 8,

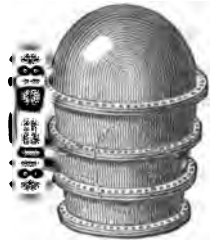


Fig. 9.

nd in use at some

outside shell and

ed to any wear at all,

ate front plate with

ad in case of need.

in Fig. 9., made

nts, with an internal

When cast iron

ers intended for high

rm of tubes of small

olf's boiler, so much

mentary committee

sisted of nine cast-

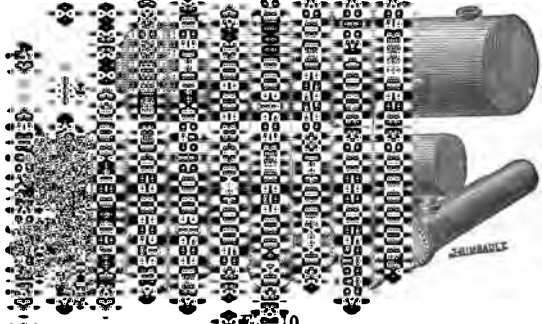


Fig. 10.

ng, set in brickwork

These small tubes were
ced transversely above
again with a still larger
details of any explosions
en obtained; but it is
t treacherous material,
fire; and that the effect
e boiler burst at once
out with great velocity,
circumstance of large
case with wrought-iron

e the shapes were most
han before. One of the
Fig. 11, with round top

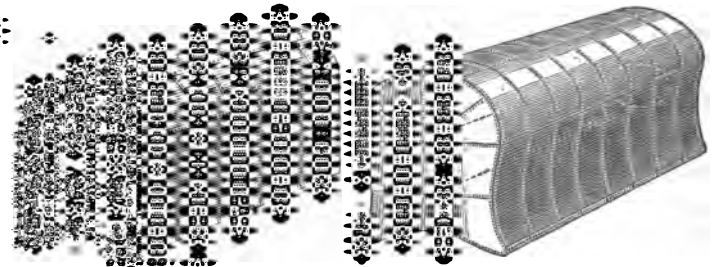
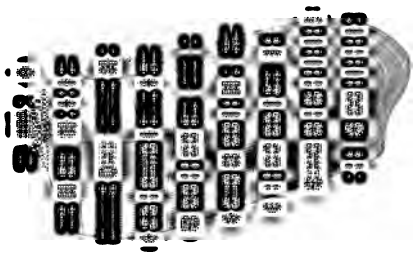


Fig. 12.

made to bear even the
th numerous stays. In
boiler the bottom was
being weakened by the
under each variation of
m must be constantly
explosion at Chester in
on improved in its steam
ncave instead of flat, as
ce was greater and also

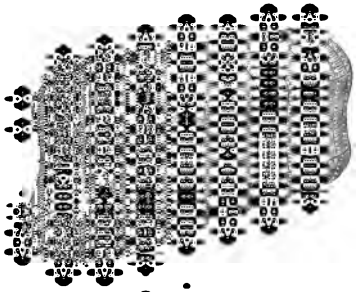
flame in the flues.

ends as in Fig 13,



correspond with the

ll required numerous



of the boiler being

explosions show the

e way at the bottom,

r in 1842, where the

they also sometimes

irection consisted in

boilers still exist that

ig. 15, so that the whole

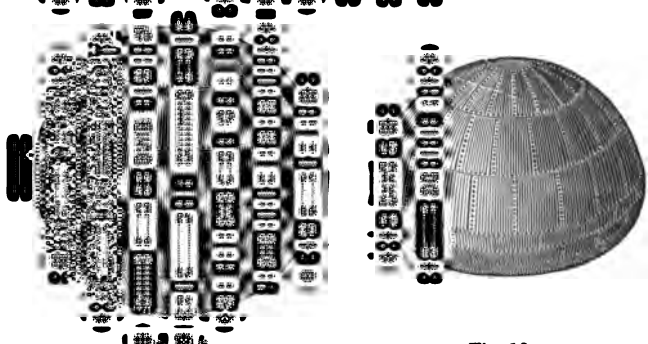
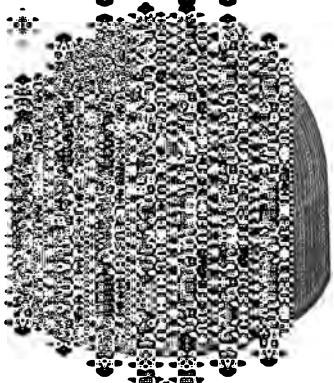


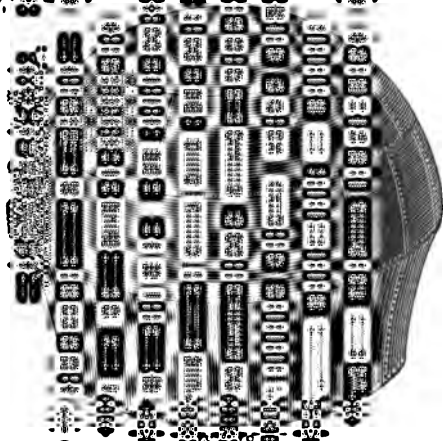
Fig. 16.

required no assistance
to alter its shape under
the great disadvantage
face for its size or cubic
y from sediment on the
al spot. The spherical
pe shown in Fig. 16, by
d convex; and afterwards
oncave bottom, with the



gle iron, as in Figs. 17

so well in the

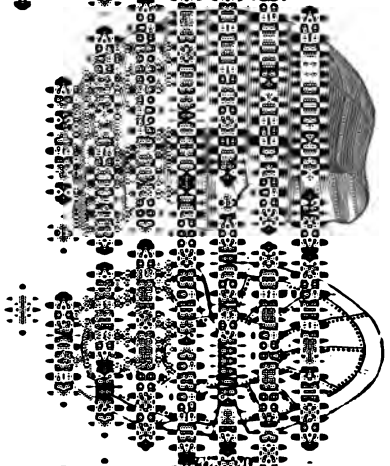


or Haystack boiler.
eat size, measuring
uch water and steam
n. Perhaps no form
because of the great
use of the inherent
ve not been obtained
ecause they seldom
ract much attention,
sitions at collieries.
wn into the fireplace
ngle iron round the
onstant springing of
; and the weakness
ng on the brickwork
t of this continued
model exhibited.

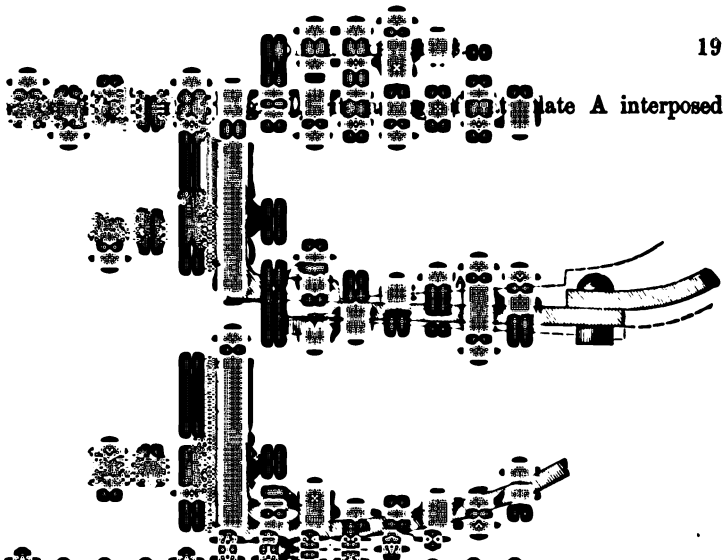
ilers upon stays for
e as 12 and 15 feet
later has been the
place at Smethwick

As the force of the

bottom giving way, and
reaction of the issuing
example that occurred
where the explosion was

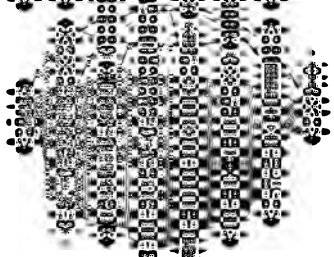


being torn off all round
into two pieces; while
in one mass, and were
kness of this boiler had
angle of angle iron, as



late A interposed

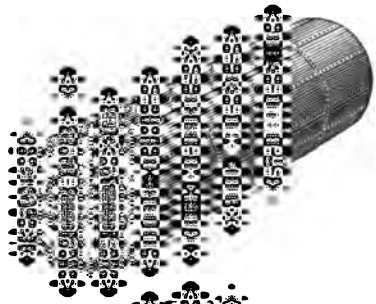
tom of the boiler;
n, as shown by the
ch was accordingly
been made to rise
pringing could not
have had to stand
id bottom; but as
the concavity was
to bear an up and
Fig. 21, and the
have been if the



hown in Fig. 23,

increased by an internal
arched and curved flue
n within the boiler before
nstruction however must
the boiler greatly. In
ated by the dotted lines,

boilers by lessening the
of the Plain Cylindrical
ends of cast iron, which
exposed to the fire, as
plosions. The flat ends
g. 24, are exposed to the



and wagon boilers, and are
ressure like drum heads,
y also require long stays
e are subject to so much
und for long together,
d cotters.

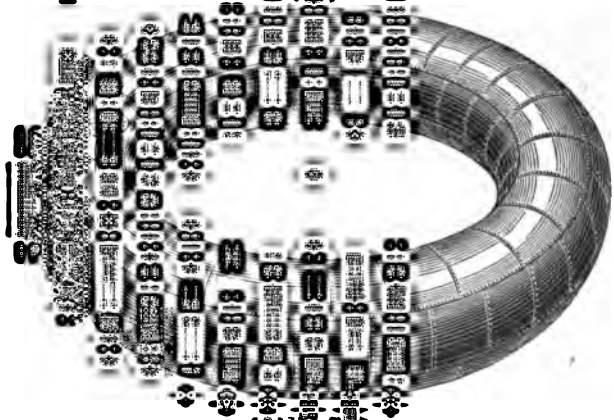
always being sprung by
or less spherical shape,
this consideration no
mispherical, as shown in

hemispherical ends

ber any other form
ag, as the whole of
re has no tendency
model exhibited.
vour of the plain
e so easily cleaned
work at every part
d equally to view.
boilers externally
ened by the action
ury from accumula-
be prevented from
to the direct action
as 70 or 80 feet, as
last furnaces, these
cks," owing to the
fierce flame for its
oler by exposure to
ave a succession of
ere great length is

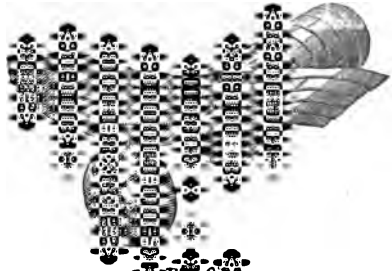
ere extreme length
until the ends met

[illegible] boiler is shown in Fig. 26,

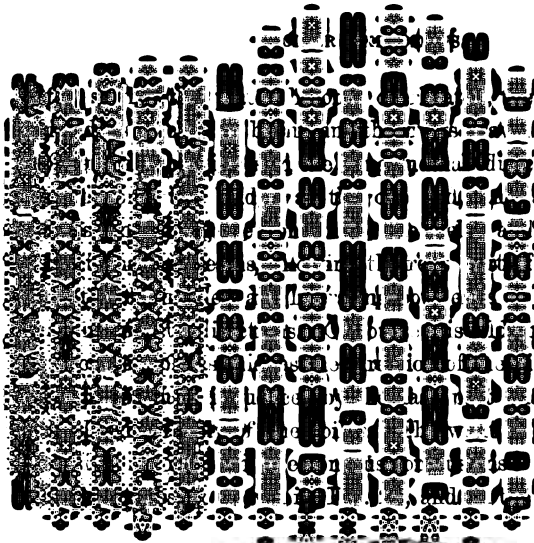


[illegible] diameter of the ring, [illegible] been found to work well [illegible] heat of six puddling

[illegible] have been very frequent [illegible] proportionate number of [illegible] positions at colliery and [illegible] Fig. 27, represents an



[illegible] 1863, and illustrates the [illegible] They generally open [illegible] which has become dete- [illegible] proper contact of the



r quality injured,
or loosened. The
tion to the sound
t the other end
then runs up each
the shell to open
the boiler, which
that an explosion
ght of the various
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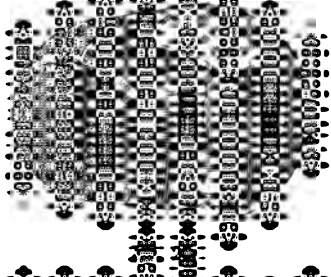
lue observation of
model exhibited,



lower part of the
he liberated part
fell some distance
side from which
us on examination,
ron of the bottom,
angle iron of the
ove. This seam
turned, and they
ached off, but not
ed the diverting
w off at a tangent,
the sound upper

ter for plain cylindrical
boilers have been used
ver by a combination of
of these known as the
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is shown in Fig. 29,

Fig. 29.

eter connected by upright
Another form called the
described at a previous

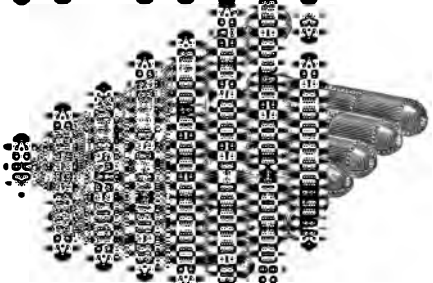

Fig. 30.

dings Inst. M. E. 1855
wo combinations of plain
an or examine internally,
am, which has to find its
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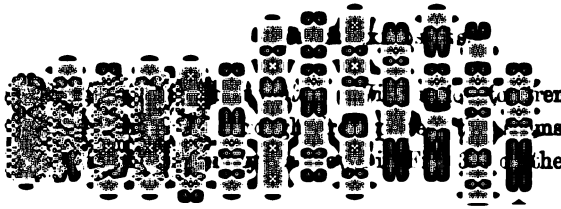
generation of steam and



rengthen the plain

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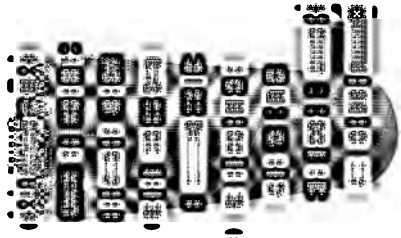

the transverse the

greatest amount of

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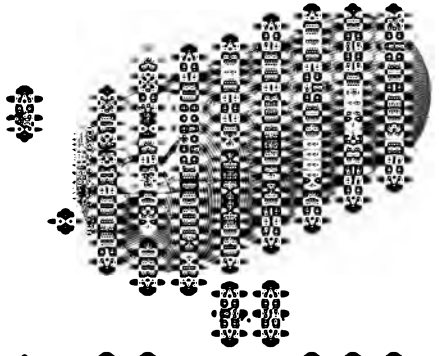
surface. These are

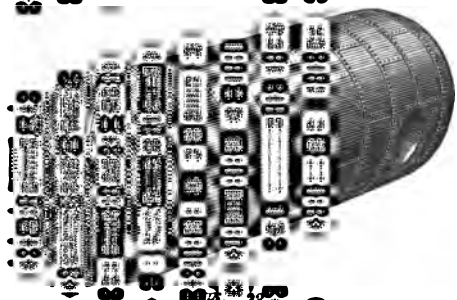
of wagon boilers,

g. 32, where a tube

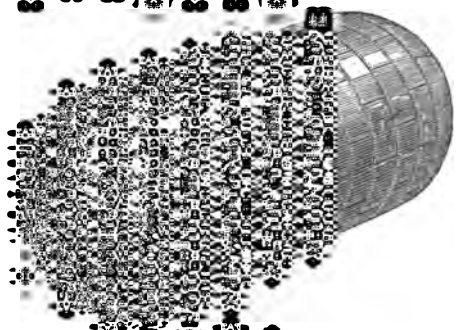


plain cylindrical

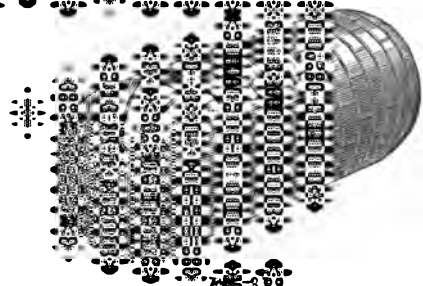
sides to the front: in



returns over the fire and



35 a tube from the back



side. The boilers in all

ition of tubes has tended

oilers in order to make

of 9, 10, and even
ted externally is
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clean on account
. When the flame
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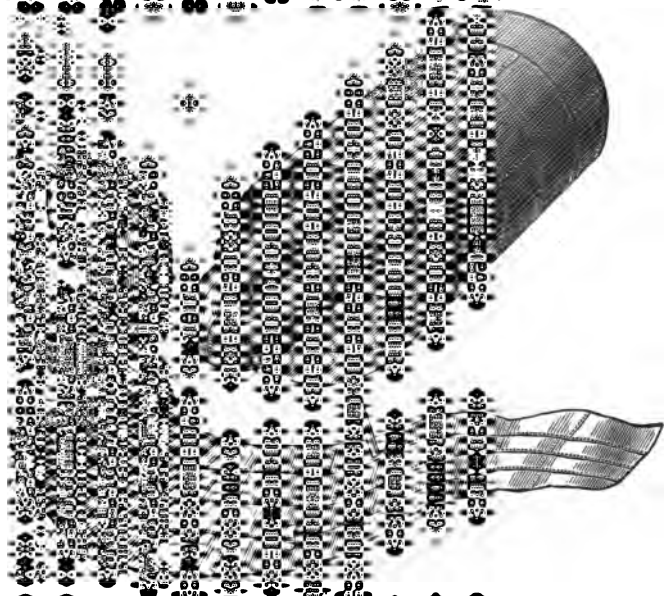
ptful whether the
eration of steam;
of water in the

taken place by
y by the failure
sketch Fig. 36,



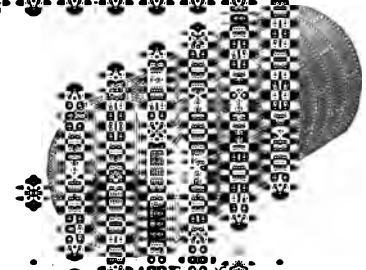
hampton in 1865,
over the fire where
ch of longitudinal
ates over the fire
seams completely

wn in one flat piece, as
ly of the boiler with the
wn away.

veral of the forms of
truction known as the
wagon-shaped end over

plain cylindrical shell
erate steam very rapidly;
n over the fire and along
nt end of the tube widens
ed fireplace, has led to
ow made of this form.
inburgh in 1821 was of a
e wagon-topped fireplace
form of boiler occurred
ampton in 1854, and at

acing the fire inside the



, as shown in Fig. 38,

ed in Cornwall gave
edingly good duty
ve them the most
great number of
that have happened,
lue boiler shown in
increased but the

iameter in the same
the two-tube boiler,
ng various particular
made to unite into
ming what is known
g. 40, and in other

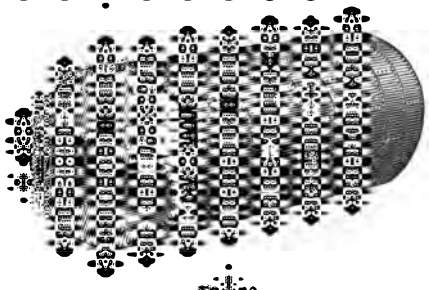


FIG. 40.

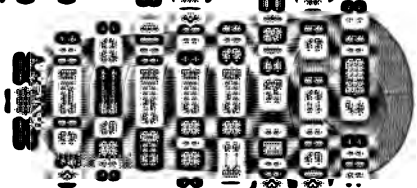
been made oval, as

ned through from end

en increased, and the
smaller transverse tubes
vantages are gained by
to greater difficulty in

se when used for high
experiments, led to
gs of different makes
which the shell and the
has taken considerable
tubes when exposed to
a great many boilers
ge tubes without the
such boilers are used in
than can be considered
oilers, one boiler after
of the tube from the want
ve still been believed
ers of this construction
extremely numerous, yet
e has been considered
A sketch of a boiler

which exploded at



from many others
ated, and was a good
esist high external
t at the support of

ular boiler internally
st tension is not also
e is in the midst of
d from it; and the
which most steam
ter above it for the
boilers heated from
nds; and the mud
uld do mischief, and
harmless.

to disadvantages
about within them
ylindrical boiler, as
erence of expansion
paratively cool shell
e out; or if the ends
in the tube, which
iron softer or more
Notwithstanding
an excellent one.

have been made to
heat from various
the plain cylindrical

times as many as eight
boiler. One of the
purpose was the Upright
, which was originally

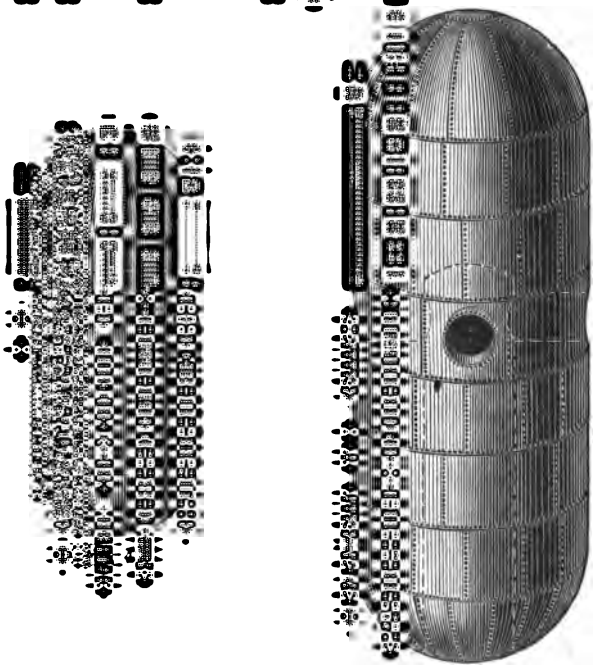
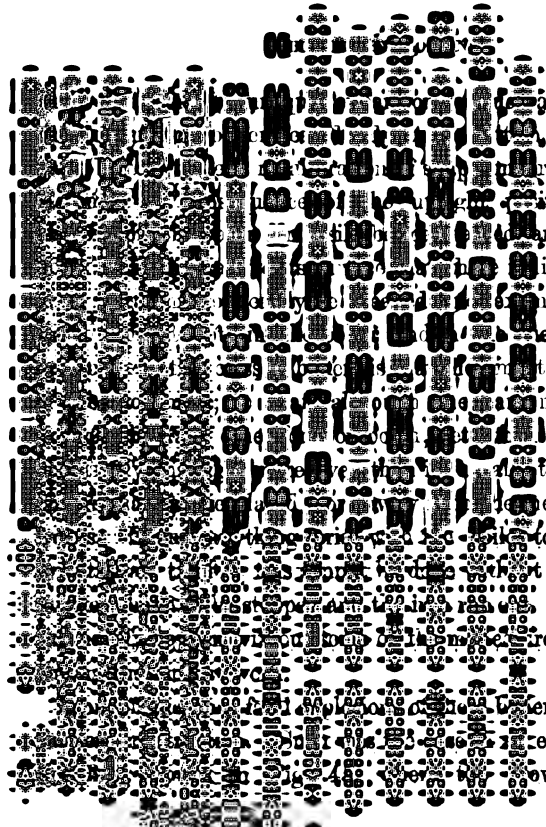
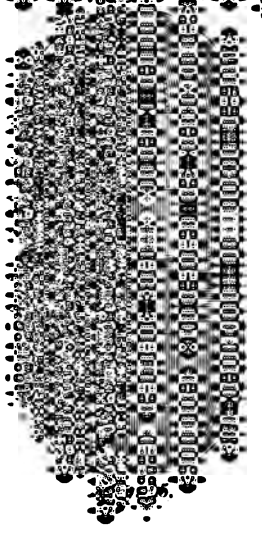


Fig. 44.

meter and 16 feet high.
diameter and 28 feet
re made for one, two,
ist of a cylinder with
central tube from the
ch the side tubes join.
portion of the shell, and
wn the centre tube into

there is great heating
nd does not strain the





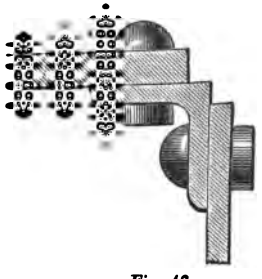


Fig. 46.

e sides of the tube by
d in Fig. 46, that the
airly sheared the angle
blown down the centre
e boiler was violently
issuing steam and water

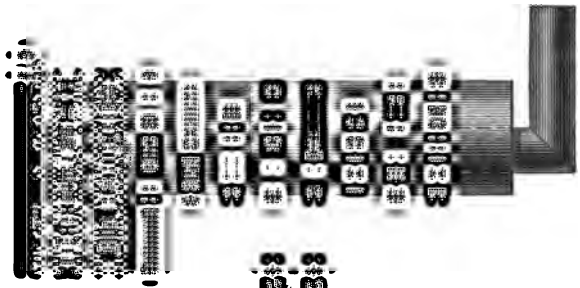
sed in connection with
nace working into each
oiler can be placed a
fatal explosions have
h 1862.

ave been much used in
boiler standing on end,
the flame passing up the
n the form of a chimney
The tube passes through
that the plate is not
by contact with water;
sion in some instances,
en lined on the inside
plate from the flame.
e of this Chimney boiler
the tube and the shell
st impossible to examine

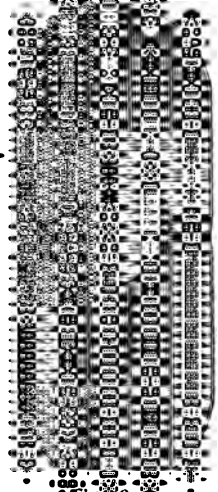
a single-furnace boiler
in Fig. 48, where the
in the previous boiler

arious shapes have been

large size that has



, with an internal
for increasing the



in such a way that
the exterior shell

1863, resulted from
me general form, but
ails of construction.

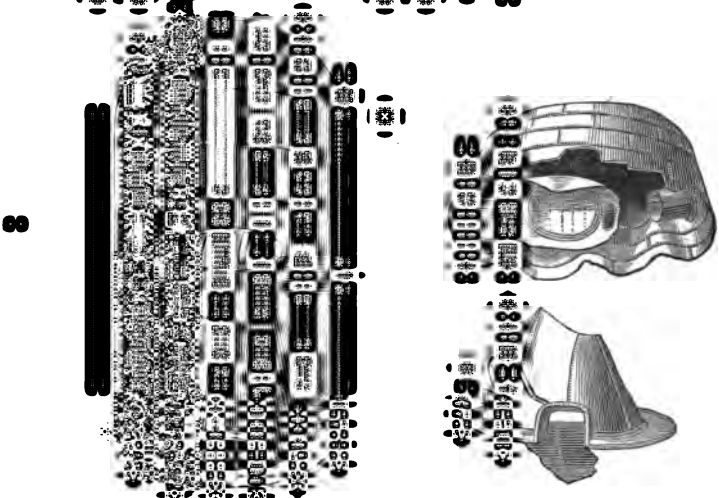


Fig. 51.

6 ft. 10 ins. at bottom, a flat annular bottom. h pressure the conical at the top of the cone, in Fig. 51. The flat the cone and side tubes, on; and the top flew up apled heap, as shown in is that a boiler of such losion.

rge and varied class of press object of avoiding pipes of small diameter, eam carriages were first ister of small pipes, set with a general receiver These were found to

have such small circulation of water that they very soon burnt out, and also led to much priming. Afterwards, narrow chambers made of corrugated plates set like the cells of a battery were tried, but without much success. The multitubular boilers of the locomotive type soon superseded all others as quick steam generators, and until lately they have been considered as almost absolutely safe from explosion. It is found however that the barrel of these boilers is peculiarly liable to furrowing, owing to the strain weakening the iron in certain lines. Perhaps no boiler shows more clearly than the locomotive how necessary it is that every part should be open to examination; and also how unwise it would be to use for stationary purposes small cramped up boilers, only intended to meet the necessities of locomotion. Many explosions of locomotive boilers have taken place; but it is not necessary to give details in this paper, as they are fully given in the published official reports of the government inspectors.

Among the form of boilers designed to obtain very rapid generation of steam, combined with increased safety from explosion, may be specially named that consisting of a system of small pipes within a shell with an artificial circulation of water, and also the boiler consisting of a cluster of cast-iron spheres, both of which have been described at previous meetings of the Institution (see Proceedings Inst. M. E. 1861 page 30, and 1864 page 61); but neither has been much used in this country at present. The boilers also which consist chiefly of small tubes hanging down into the fire, with smaller tubes or other arrangements within them for securing a natural circulation, deserve mention, as they appear successfully to accomplish that end.

The principle of all these small boilers appears to be that only a small quantity of water should be contained in them, so that there should not be a reservoir of danger in the shape of a mass of highly heated water ready to be converted into steam if a rupture takes place: and it cannot be denied that this is an advantage. But on the other hand these boilers of small capacity, which evaporate their whole contents in a few minutes, are subject to new dangers from

that very cause; and although admirably adapted for purposes where steam is wanted quickly on a sudden emergency, as in the case of fire engines, or where the generating power required varies each moment, as in the locomotive, they are for the most part ill adapted for ordinary stationary purposes, such as the mill or the colliery. They require constant firing and vigilant attention to the feed, and cannot be left for a time with safety like the ordinary stationary boilers. It has to be borne in mind also that the very reservoir of danger so much dreaded is also a reservoir of power, which assists in the steady maintenance of the machinery in motion. The large mass of water heated to the evaporating point, the heated brickwork of the flues, and the large fireplace, are so many assistances to regularity, and enable the man in charge to attend to his other duties without the risk of spoiling the boiler or letting down the steam by a few minutes' absence from the stoke hole. Steam employers are found at present to prefer the known dangers of the large boilers to the supposed safety of small boilers, which they fear are troublesome in practice.

Many of the early boilers were rendered weak by the injudicious manner of arranging the seams. The longitudinal seams were made in a continuous line from end to end, as shown in Fig. 24, page 20, with the transverse seams also continued completely round the boiler, so that at the corner of each plate there were four thicknesses of iron. The crossing of the seams, as in Fig. 25, page 21, adds much to the strength, and also often prevents a rent from continuing forward to a dangerous extent.

It is scarcely requisite to mention the necessity of good material and workmanship to secure strength in a boiler, however perfect the design. If the plates are of weak and brittle iron, or imperfectly manufactured, they will never make a good boiler. Apart from the strain upon the boiler when at work, the iron has to undergo the strain of the necessary manipulation, shaping, and punching, during the construction of the boiler. If the plates forming the boiler are not well fitted to their places before the rivet holes are

by using the drift in
en using imperfect
d with each other;
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which is sure to show
most unequal internal
to work at all; and
pansion causes undue
imately to disaster.
ing were exhibited to
own in Fig. 52.

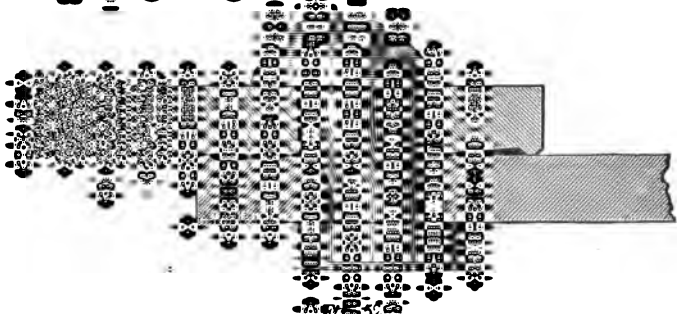


Fig. 52.

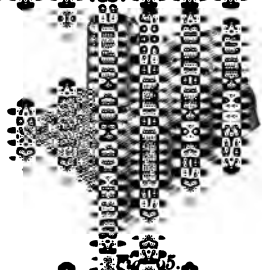
much lessened by the
are fixed upon the
e of this defect. Not
of the boiler in one
Steam domes are
el of the boiler, the hole
er of the dome; and
been made square or
as shown in Fig. 53.
t properly arranged
oilers they are often
inal direction of the
as in the sketch,

in 1865. This boiler

Fig. 54.

er, and yet the manhole
within a few inches of one
e iron, which was not
e strength at the small
the manhole that it gave
ole lid, after which the
reaction across several

ment of the manhole is
inches by 14 inches was



only 2 ft. 6ins. diameter,
ate for it. The repeated
combined with the pressure
way out through the
curred at Birmingham

The preceding examples have shown how explosions often result from faults in the construction of boilers; and the following instances illustrate the explosions caused by mischief arising during working. A boiler perhaps more than any other structure is subject to wear and tear; and let it be worked ever so carefully, it will seriously deteriorate. The wonder is, considering the work they have to perform, that so many boilers are found which have worked twenty, thirty, or even fifty years without explosion. The terms wear and tear however are too vague for this subject, and the mischief met with must be considered under distinct heads.

There is no doubt that the thing most to be dreaded for boilers is corrosion; because when the plate is once thinned, it cannot be strengthened again, but must remain permanently weakened. Corrosion the more deserves attention because it is easily detected by moderate vigilance, and can generally be prevented by moderate care, or by the boilers being so arranged that they can be readily examined in every part. Corrosion has been the direct and unmistakeable cause of a very large proportion of the explosions that have happened: it occurs both inside and outside the boiler, according to circumstances, and attacks the iron in various ways and in different places.

Internal corrosion sometimes takes place from bad feed water, and its effects are different in extent in the different parts of the same boiler. It very seldom thins the plate over a large surface regularly, but attacks the iron in spots, pitting it in a number of holes. These are sometimes large, as if gradually increasing from a centre of action; and sometimes small, but so close together as to leave very little more space whole than that which is attacked. A very curious example of the latter was exhibited to the meeting, and shown in Figs. 56 and 57, cut from the lower part of the shell of a large tubular boiler externally fired. The corrosion was greatest along that part of the shell most exposed to heat, and was so extensive that two boilers exploded simultaneously. The boilers had been at work sixteen years, but the corrosion commenced about eight years before the explosion, when the feed water was rendered corrosive by being obtained from some iron mines.

1864. The corrosion

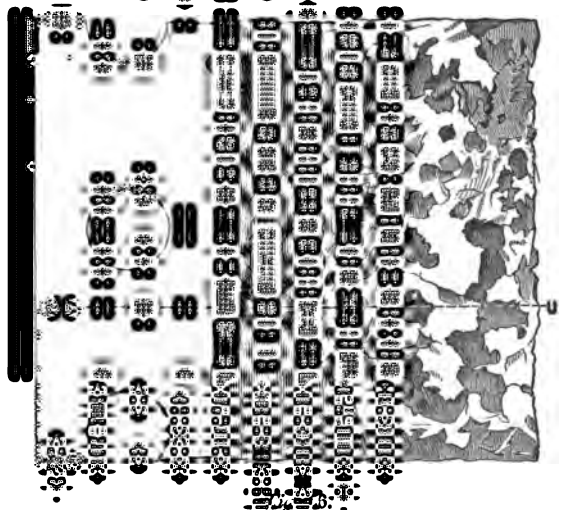


Fig. B.

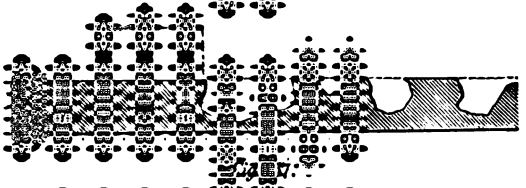


Fig. C.

was not considered
to which it extended
in the half size section,
was exhibited to the
en from the sweep plate
ch had worked about ten
, and attacked the iron
scale. The protection
ve feed water is worthy
ed it is seen that the
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cts over the hollow, as

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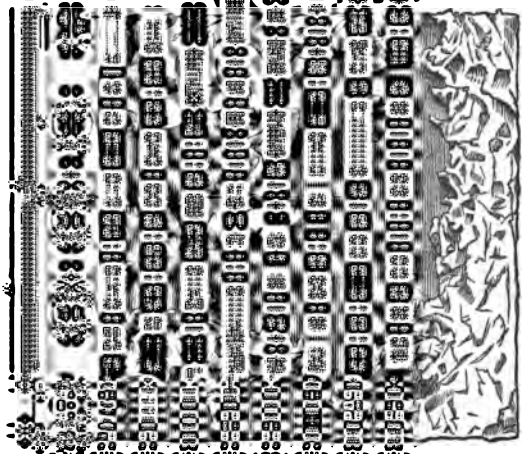

that through which

here boilers are fed

of chemical works

intervals into the

pots, but causes deep

supposition that the

the cooling of the

hat a piece of about

When the boiler is

with the corrosive

and causes corrosion.

may be seen, and if

njured surface. In

future working each of these blisters forms a constant unprotected point for attack. It is frequently seen further that such corrosion is arrested if water be used which deposits scurf; but fresh blisters and renewed corrosion will result from a return to the use of the bad water.

The internal corrosion called furrowing has proved a frequent cause of explosion, especially in locomotive boilers. It differs from other corrosion by being in deep narrow continuous lines with abrupt edges. It will sometimes go completely through a plate; and is found where a sudden change of thickness occurs, either along the lines of the seams, or opposite the edge of angle-iron attachments. This effect is supposed to be due to the alternate springing of the plates under each variation of the pressure or temperature, causing the line of least resistance to receive a strain somewhat similar to that produced by bending a piece of iron backwards and forwards for the purpose of breaking it. This line of injury is exposed to constant attack from corrosion, because the scurf is always thrown off from it.

External corrosion is a far more frequent cause of explosion in stationary boilers; and it arises from many causes. The most frequent cause, although the most easily detected, is leakage from the joints of the fittings on the top of the boiler, which are too frequently attached by bolts instead of rivets. This evil is much increased when the boilers are covered with brickwork, which holds the water against the plates, and hides the mischief from observation. It is astonishing to find how much damage is allowed in this way to go on without attention, until the tops of boilers are corroded so thin that little holes burst through. These are sometimes found stopped with wooden pegs or covered by screwed patches of plate, either of which cause leakage that hastens the mischief, as shown by the sample exhibited. Boilers exposed to the weather will of course become corroded like anything else made of iron and not painted; and yet so much mischief is sometimes caused by leakage beneath improper covering that exposure may almost

be said to be the smaller evil of the two, as it is better to see what is going on than to rest in false security. No covering will be found cheaper, or better, in the long run, than a roof, which prevents the loss of heat by exposure, and yet allows free access to all the fittings and joints on the top of the boiler.

Some examples of the evils of covering can be given that have come under the writer's observation. A set of boilers had been well covered by arches of brickwork, so built as to keep out all water, and also set so as to touch the boilers only at intervals, leaving a space generally of a few inches. After about seven years' working, the whole of the tops of the boilers were discovered to be dangerously thin, and had to be renewed. The cause was leakage from the joints of fittings and seams of the boilers, and the issuing steam had been drawn along the space between the boilers and the arches, and had escaped at a place where it had not attracted notice. In another case, a somewhat similar set of boilers were covered with ashes, to prevent the loss of heat by radiation; and the rain and the leakage beneath the ashes, in conjunction with the corrosive matter from the ashes themselves, thinned the tops of the boilers to a dangerous extent in less than two years. A sketch of the corrosion caused in this instance by covering with ashes is shown in Figs. 60 and 61.

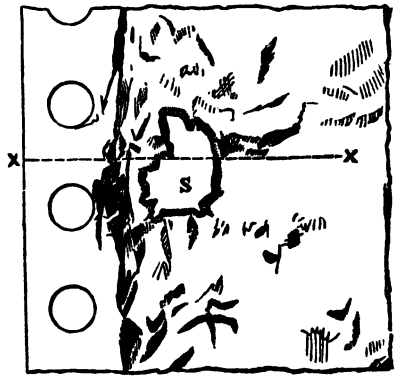

Fig. 60.

Similar mischief has been noticed in boilers covered with sand,

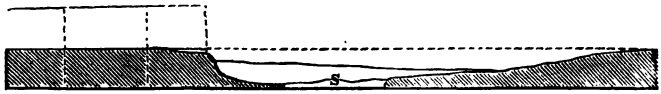

Fig. 61.

as shown in the sketches Figs. 62 and 63, which represent an instance of corrosion after eight years' working; although nothing

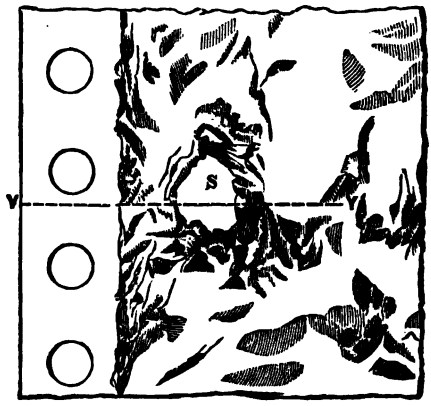

Fig. 62.

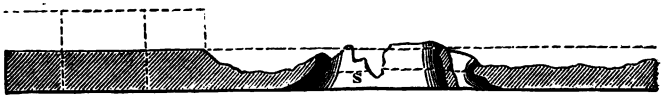

Fig. 63.

forms a better covering than sand for preventing loss of heat by radiation. In both these examples it will be seen that the corrosion has continued until the thickness of the plate has been so eaten away that a hole has been burst out at SS. A very good covering is formed by brickwork in cement; or various cements made for the purpose, which adhere to the surface of the plate and yet show leakage; or such materials as sacking or felt; or sheet-iron casing, leaving about 6 inches of air space all round the boiler.

hey hide the boiler
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e caused explosion

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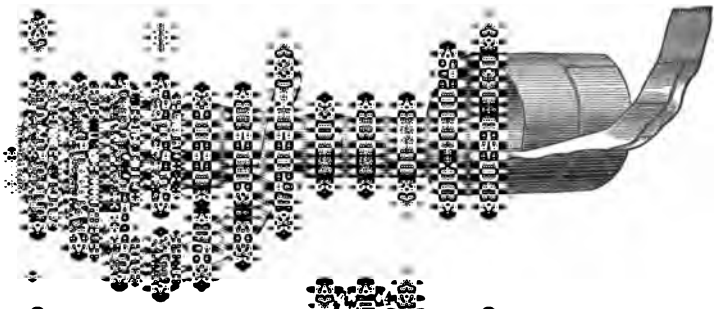
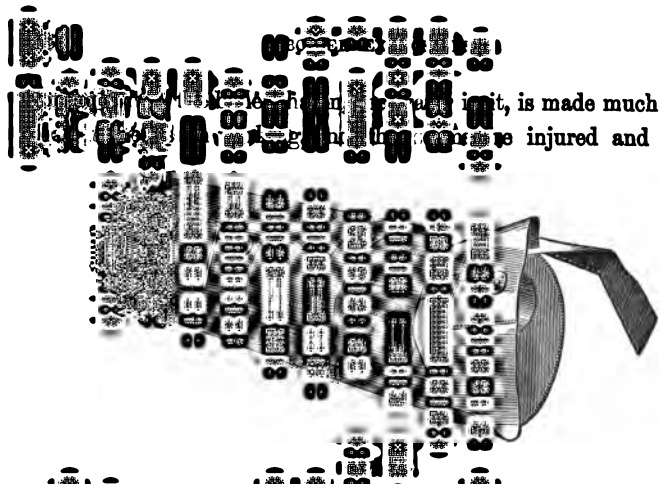
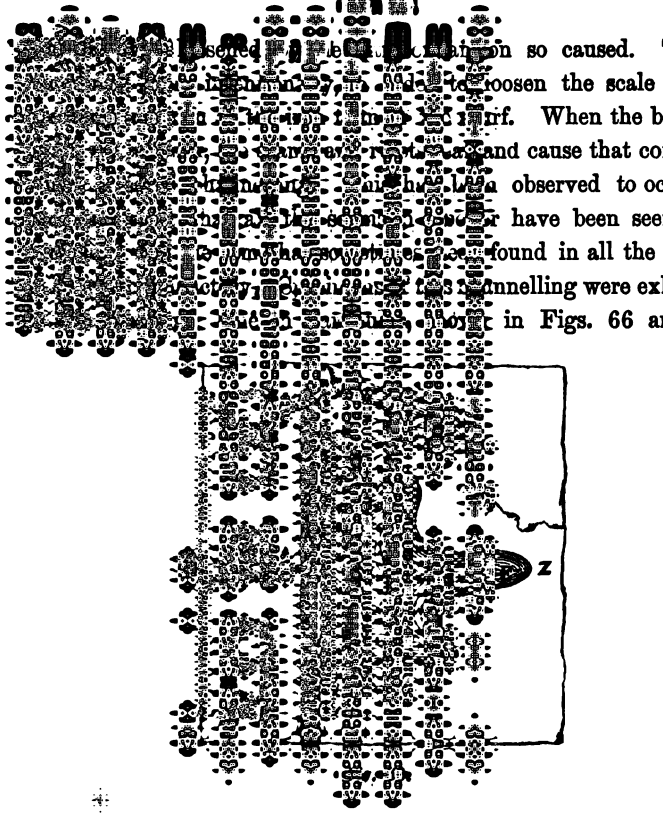


he boiler.

n the side flues of
boilers are emptied
day night, and long
es has cooled; and




Z

deserves attention, as it shows the effect of a jet of steam and

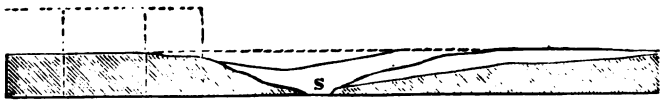
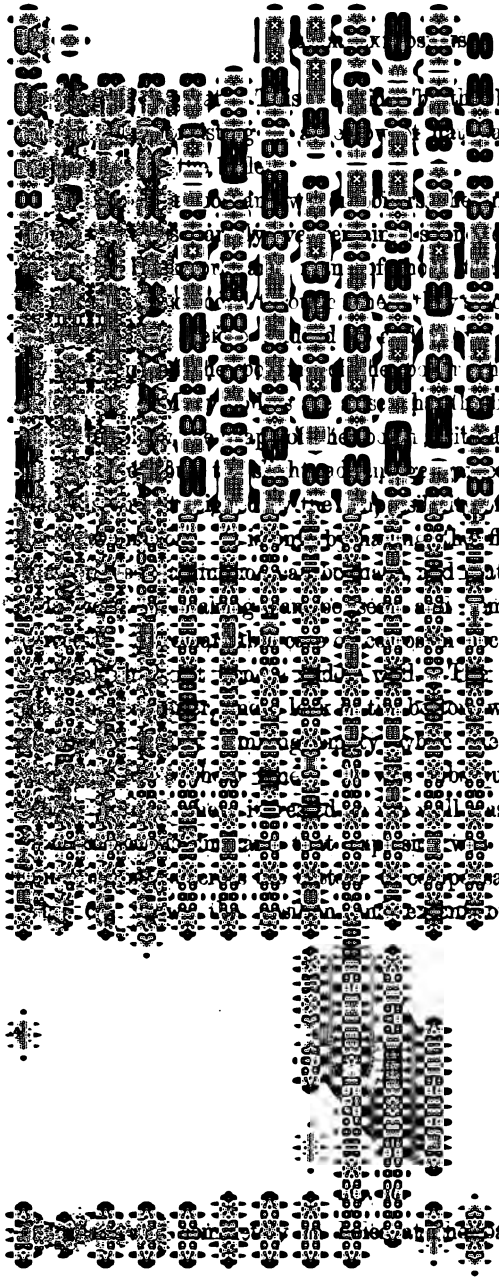


Fig. 67.

water from the leaking rivet R, in cutting a series of channels into the plate along the course of the dotted lines EEE, and producing a hole in the plate at S. This corrosion had been going on for about four years, but was in a part of the boiler seldom seen in ordinary examination. Many explosions have resulted from this form of corrosion; for when a rent is once made, the fracture continues along the thinned channel of the plate.

The corrosion most to be dreaded, because most difficult to detect, is that which takes place where the boiler is in contact with brickwork; and it is found alike in all forms of boilers set in brickwork. When found at the part where the side flues are gathered in at the top against the boiler, it is usually occasioned by the leaking of fittings or feed pipes, or by rain being allowed to run between the boiler and the brickwork. More than one explosion has been caused by the droppings from a roof being allowed to fall upon the tops of the flues. When the corrosion is found at the point where the bottom flue walls touch the boiler, it is frequently caused by the leaking of seams that have been strained by the weight of the boiler; and this often arises from want of care to replace the brickwork, after repair of the boiler or flues, in such a position as to take again its proper proportion of the weight of the boiler. Cases have been met with where the shape of the bottom of large boilers has been quite altered by such means. The brackets on the sides of heavy boilers have not only been strained so that the rivets or bolts have leaked and caused corrosion, but they have also bent or cracked the side plates of the boiler. The bracket shown at B in Fig. 53, page 40, made of only an angle iron with a piece of plate attached, is especially liable to cause injury if the brickwork is not rebuilt close up to the angle iron, as the



better form of bracket

ir-iron rivetted at top

ngle where the bottom

r long when in contact

t exploded have been

od upon the brickwork.

in Fig. 7, was caused

ere it was set on the

brickwork of the flues is

s little space between

d in increased heating

f getting into the flues

flues sufficiently roomy

t the indications on the

medied, and corrosion

curred in a boiler with

flues were too narrow

was only discovered by

engine pumps were

uently found that the

as extensively corroded

only prevented by the

ate for the oval shape.

f the corrosion, and

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ave been going on

be the cause of an
nply give way and
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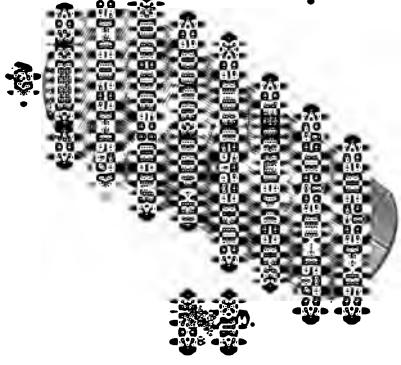
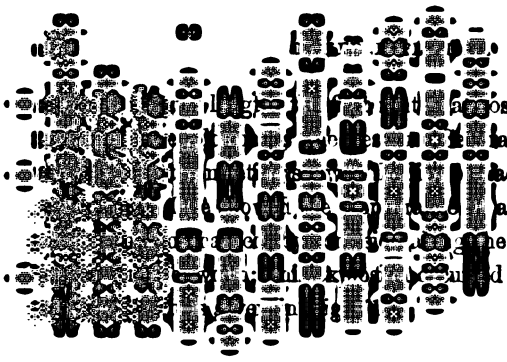
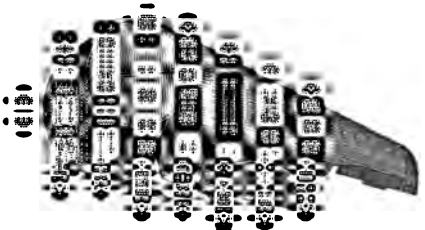
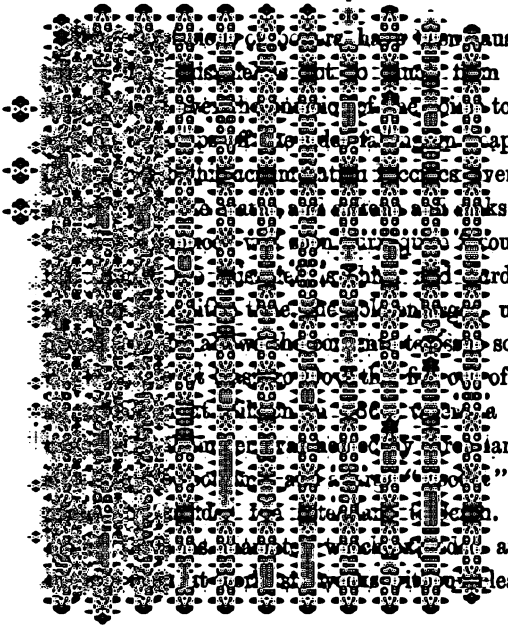
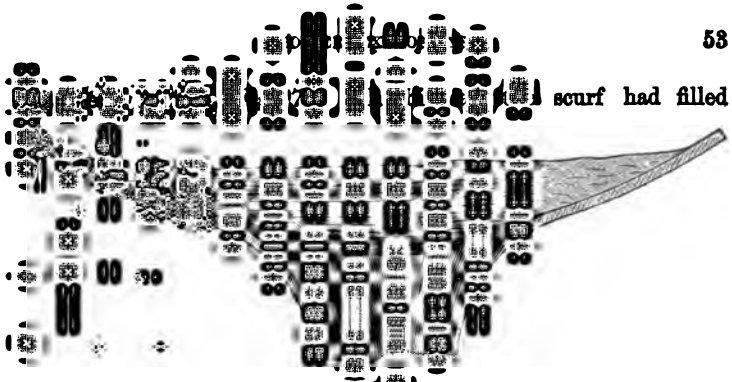
If the corrosion





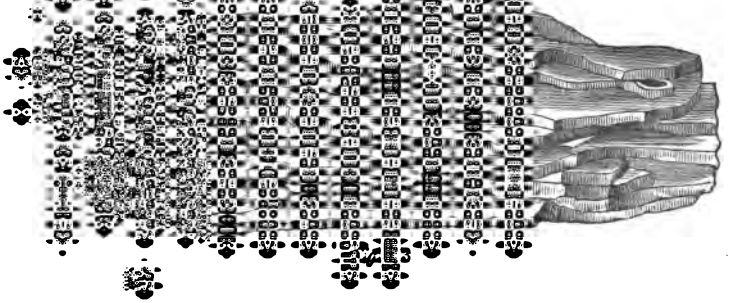






scurf had filled

les at the bottom,
hard description;
urve, and thinned
nch.
ured, and the plates
umulation of mud.
s very full of mud,
uring the week but
ch time the deposit
ly disengaged again
, but hardened into
injuries to the plates
mes cause that first
ncture and leads to
ited to the Meeting
ships, carelessly left
boiler, as seen in
left in the boiler



and forming a nucleus for the scurf to accumulate upon. Other specimens show that foreign matter must have been put into the boiler to stop leaking.

Accumulations of scurf in the feed pipes at the point of entrance into the boiler have also caused explosion by stopping the supply of water. The same result is caused by the freezing of the water in the pipes which are exposed, and each winter one or two boilers are injured or exploded from this cause, especially small household boilers placed behind kitchen grates. Scurf cannot be considered so great an evil as corrosion, since it can be removed, and if this is done in time, the boiler is restored to its original condition.

The advantage of a pure water, which does not deposit scurf, is so great for the supply of boilers that it is always worth while to go to considerable expense for obtaining it; or to take some steps for purifying the feed water as much as possible. If it is only mud mechanically suspended, which would deposit by gravity on the bottom of the boiler, frequent use should be made of the blow-off apparatus. If the impurity is light enough to be carried to the surface in the form of scum, the blow-off apparatus should discharge from the surface of the water as well as from the bottom. If the impurity is chemically suspended in the water, some one of the many substances which form the refuse from various manufactures, and which may contain suitable ingredients, should be used to counteract the effect of the impurity. Common soda will answer the purpose perhaps better than anything else. It must not be forgotten however that the blow-off apparatus must afterwards be used more frequently, to rid the boiler of the foreign matter, or the mischief will be increased. In marine boilers, constant attention is necessary to get rid of the saline deposit; and in stationary boilers using impure water an equally systematic attention is needed to get rid of the earthy deposit.

Perhaps no cause of explosion is oftener mentioned than shortness of water, and this is not unfrequently coupled with turning on the feed suddenly into an overheated boiler. Many explosions have been attributed to this cause, when closer investigation would have

tance, shortness of
Abercarn in 1865,
, which collapsed
and the sides of
although exposed
rked through the
In this case the
the tube, and not
hat if a boiler runs
oiler, there must
ted with any other
w-off pipe or any
but of shape upon
would happen. If
feed were turned
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hot, and so much
aring the pressure,
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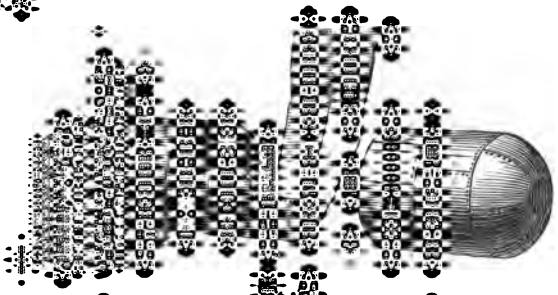
line, as shown in



before the over-
e, as usual, carried
r would gradually
he heat of which
poration than the

ordinary safety valves would carry off. The danger would not arise so much from the excess of steam generated by the heat accumulated in the heated plates of the boiler, as from the injury and strain that would be caused to the plates by the undue expansion and sudden contraction, especially as this action would take place on only a portion of the boiler. A singular case, bearing on this point, may be mentioned. A four-furnace upright boiler, like that shown in Fig. 44, happened to run so nearly empty, through the accidental sticking of the self-acting feed apparatus, that the level of the water sank to the top of the hemispherical end forming the bottom of the boiler. The feed apparatus then became released of itself, and, the feed being turned full on, the water gradually rose until the whole occurrence was only discovered by the leaking at the seams that had been sprung, which caused so much steam in the flues as to stop the working of the furnaces. The overheating had been sufficient to buckle the plates, and in one place a rupture had almost commenced; but there was no explosion. By way of direct experiment upon this point, boilers have been purposely made red-hot and then filled with cold water, without causing explosion.

It has been supposed that boilers sometimes explode from overheating without the water level being below the usual point, or without the accumulation of scurf previously alluded to, but simply by the rapidity of the evaporation from an intensely heated surface causing such a continuous current of steam as to prevent the proper contact of the water with the heated plate. Such has been the cause assigned for the explosion of a three-furnace upright boiler at Birmingham in 1865, shown in Fig. 75. A piece of plate about 3 ft. by 1½ ft. was blown out of the side, at a place where an enormous flame impinged continually. The plates had first bulged out, and then given way in the centre of the bulge, each edge being doubled back and broken off. There was no positive evidence as to the water supply; but the crown of the centre tube, which was much above the bottom of the part blown out, remained uninjured.

A somewhat similar case was that of a large horizontal boiler

in 1865, as shown

es, one of which

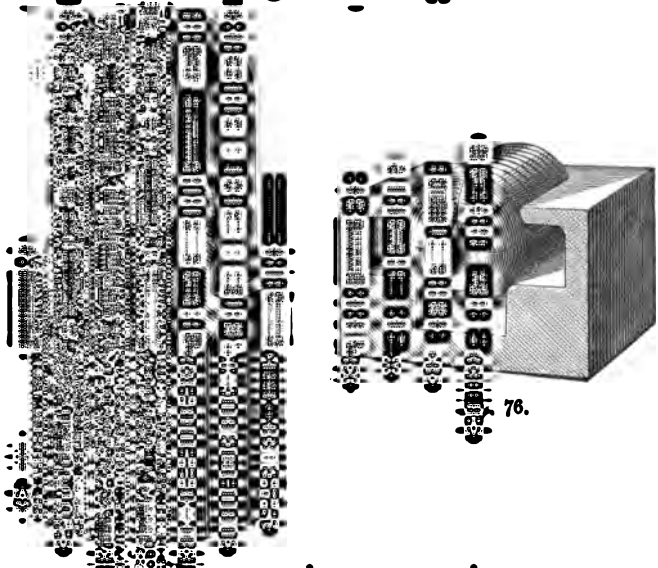


Fig. 76.

one on each side;

of the boiler. The

t end, and the top

e first instance, but

ng, although not so

ely rapid ebullition

am had to pass up

l, produced such a

the top of the tube

oration of the iron

1864, and another

boilers had worked

When an explosion

en properly welded

ound when put in,

and escaped notice; but when the plate that fails is found to be brittle and of bad iron, the fault is rather attributed to the effect of working than to original bad quality. Of course this is not always the case, as the injury done to plates by overheating has been already explained. Pieces of plate have in some cases been erroneously pronounced to be deteriorated by work, which have been taken from situations in the boilers where they were not exposed to any action of fire that could cause overheating; and therefore in reality the injury could only have taken place when the boiler was being made, by burning the iron in bending it to the required shape. A frequent cause of fatal injury to boilers is injudicious repair, whereby the crossing of the seams is destroyed, as in the explosion at Wolverhampton in 1865, previously referred to and shown in Fig. 36. Moreover the edges of the old plates, already tried by the first rivetting and the subsequent cutting out of the rivets, are frequently strained again by the use of the drift to draw them up to the strong new plates; and many a seam rip is thus started which ultimately causes explosion.

Many explosions have been caused by the want of proper apparatus for enabling the attendant to tell the height of the water and the pressure of the steam, and also by the want of sufficient apparatus for supply of feed water and escape of steam, or by the failure of one or other of these; but such explosions can only be referred to generally in the present paper. The mountings on a boiler are usually so open to observation, and the importance of having them good and efficient is so universally acknowledged, that much remark is not needed. Mention has already been made of the sticking of self-acting feed apparatus as a cause of mischief, and similar failures of floats and gauges have constantly happened; but this should by no means be considered to condemn self-acting apparatus, either for assisting in the steadiness of working, or for giving warning of danger. The apparatus however should be relied on for assistance only; and an attendant cannot be called careful who leaves a boiler dependent on such apparatus without watching. The self-acting principle has been seen by the writer applied in a novel and useful way in a recording pressure gauge, which proved the more interesting as it

had shown the actual pressure of steam at the time of the explosion of one of the boilers with which it was connected.

Among the numerous boiler explosions that have been attributed to over-pressure through deficient arrangements for escape of steam, in many cases the safety valves have been placed on the steam pipes in such a manner that the communication with them was cut off whenever the steam stop-valve was shut, which is just the time when the safety valves are most wanted. Safety valves are too often found needlessly overweighted; and it is believed that many boilers are constantly worked with safety valves so imprudently arranged and weighted, that they could not carry off all the steam the boilers would generate without a very great increase of pressure.

It is concluded that enough has now been said to show that boiler explosions do not arise from mysterious causes, but generally from some defect which could have been remedied if it had been known to exist. It only remains therefore to consider what is the most ready and efficient way to discover the true condition of a boiler. It has been maintained that this end is best accomplished by what is called the hydraulic test, in which a pressure of water is maintained in the boiler for a given time at a certain excess above the working pressure. This test is undoubtedly useful so far as it goes, and is perhaps the only one that can be applied to boilers with small internal spaces, such as locomotive boilers, not admitting of personal inspection over the whole of the interior; and it is also admirable for testing the workmanship of a new boiler. But on the other hand the conditions of a boiler at work are so different from those which exist during the hydraulic test, that this alone cannot be depended on; for old boilers have been known to stand this test to double their working pressure without apparent injury, although known to be dangerously corroded. The difficulty also of seeing or measuring the effect of the hydraulic test upon large boilers set in elaborate brickwork is so great that little practical benefit has resulted in many cases.

It is believed by the writer that the surest way to ascertain the true condition of a boiler is to examine it at frequent intervals in

every part, both inside and outside; and as this can only be done when both the boilers and the flues can be readily entered, it is specially important that facility for examination should be made a consideration in selecting a construction of boiler. Permanent safety should be considered as an element of economy, in addition to its still higher importance in reference to the preservation of life.

BRIEF ABSTRACTS

FROM REPORTS ON

STEAM BOILER EXPLOSIONS,

PRESENTED TO THE

MIDLAND STEAM BOILER INSPECTION & ASSURANCE Co.,

BY

EDWARD BINDON MARTEN,

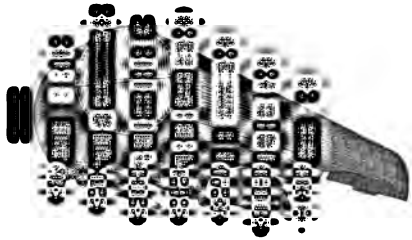
CHIEF ENGINEER TO THE COMPANY.

Description is shortened as much as possible, and facilitated by slight sketches, showing the position of the fragments or line of fracture, and the general construction of the Boilers.

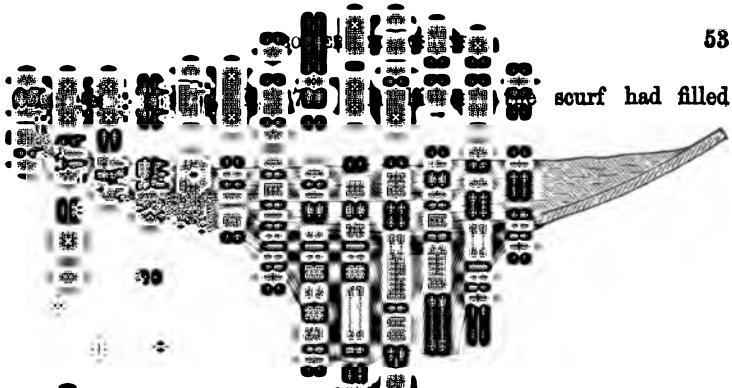
REPUBLISHED BY THE PERMISSION OF THE COMPANY.

STOURBRIDGE: R. BROOMHALL, PRINTER, HIGH STREET.
1869.

st sure to continue until
al of the small models
acture in various cases of
a plain cylindrical boiler
whole length where it
at Wigan in 1865, and



used by accumulation of
scurf being gradually
to a dangerous thickness
aps on the bottom. The
erheated, because not in
ts down into a "pocket,"
ough. If the scurf that
rd enough to resist the
until the scurf suddenly
so violently as to disturb
of the grate. Such was
large plain cylindrical
large fires placed side by
" burst out over the third
A similar pocket in a
at Dudley in 1864, after
eaning, is shown in the



scurf had filled

es at the bottom,
hard description;
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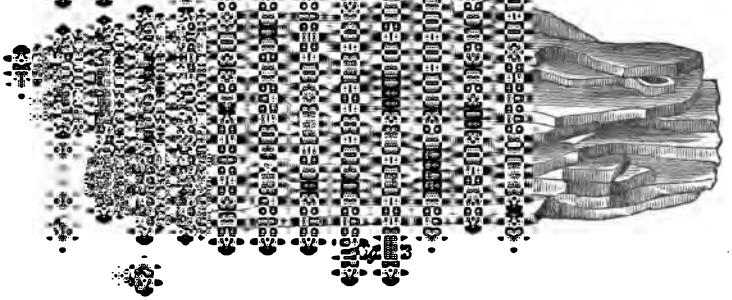
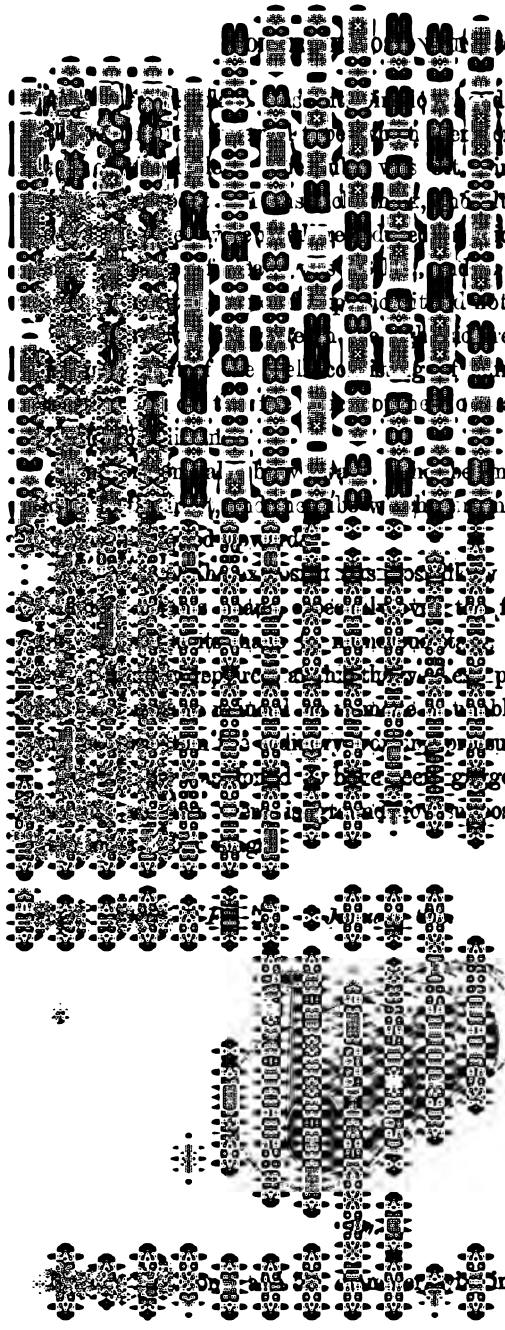
nch.
ured, and the plates
umulation of mud.
as very full of mud,
uring the week but
ch time the deposit
ly disengaged again
, but hardened into
njuries to the plates
mes cause that first
ncture and leads to
ited to the Meeting
hips, carelessly left
boiler, as seen in
r left in the boiler





1 *killed* 1 *injured.*

stance, shortness of
Abercarn in 1865,
e, which collapsed
e and the sides of
, although exposed
orked through the
In this case the
the tube, and not
hat if a boiler runs
boiler, there must
ted with any other
low-off pipe or any
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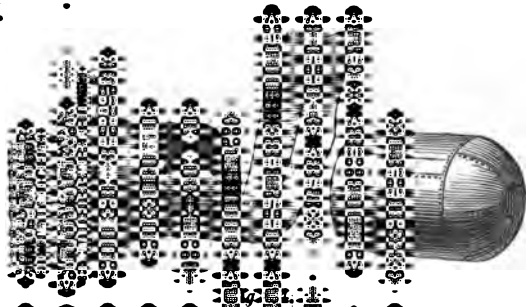
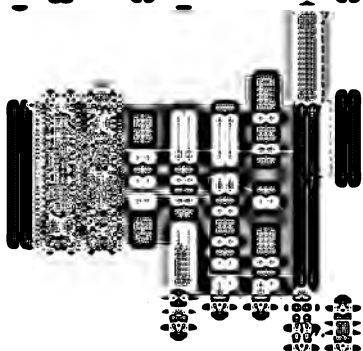


before the over-
re, as usual, carried
er would gradually
the heat of which
poration than the

1 *injured.*

1 *Killed,* 2 *injured.*



ameter in the barrel,
n. wide, 2ft. 4in. high,
fire box, two 12-inch
e back of the barrel.
an exterior smoke-box
with one spring safety
there was no pressure
bolted on so that the
aning, but it had been
nd it was nearly full

at and unstrengthened,
nd was driven into the
reared against a wall,

very dirty state, caused
per contact with the
not admit of proper
r the proper protection

1 *killed*, 3 *injured*.

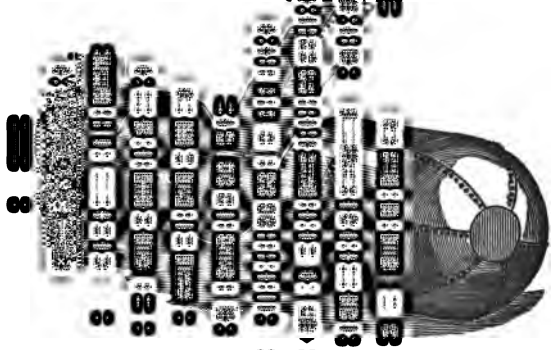
, 30ft. long and 6ft.
ond from the engine
e years, then remained
rs. The boiler was
hes diameter, a float
than once repaired
m over the fire had
explosion, but not
d just been started
he boiler had been

pened out flat, and
rt hemispherical end
ar and right hand.
a mass, and after
ds.

from the failure of a
d by age, and over-

1866.

h. 1 *killed*, 4 *injured.*



ical ends, 23ft. long, and
s set so as to be fired
was seldom used. The
nace, the neck of which
flame was carried by a
the stack on the right
ed with a 4¼-inch safety
ted that the latter had

the left hand side had
and 4th rings of plates
etached from the boiler.
thrown some distance to

side of the boiler became
t bulged outwards with
open. The over-heating
ter, but it might possibly
heat of a mill furnace
ater line, leading to such
act of the water to keep

[illegible] 1 *injured.*

[illegible] in a shed, but no [illegible]

[illegible] 1 *injured.*

[illegible] ve been obtained.

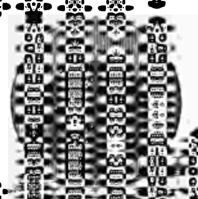
[illegible] 1 *injured.*

[illegible]

[illegible] ter, with one tube [illegible] re were no strength- [illegible] -hand, and had only [illegible] it exploded.

[illegible] engthening rings.

[illegible] 1 *killed.*



[illegible]

[illegible] 9in. diameter, tube [illegible]

[illegible] tch on the left side [illegible] it was slightly out [illegible] he top being thrown

[illegible] 66.

[illegible] evidence of shortness

[illegible] was too weak to sustain

7 injured.

[illegible] not injured, it is only [illegible] imprudence of placing [illegible] ller was beneath a work [illegible] ne displaced, allowing [illegible] n rushed into the room

1 killed.

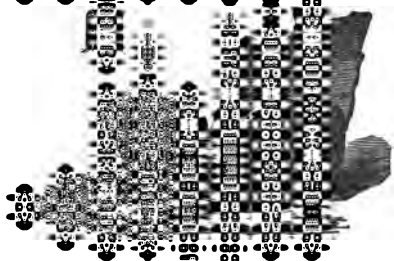
[illegible] ces, connected into one

[illegible] sed, and slightly rent, [illegible] e attendant.

[illegible] per level, allowing the [illegible] unable to bear the

[illegible] nsible plug, but they

1 killed, 1 injured.



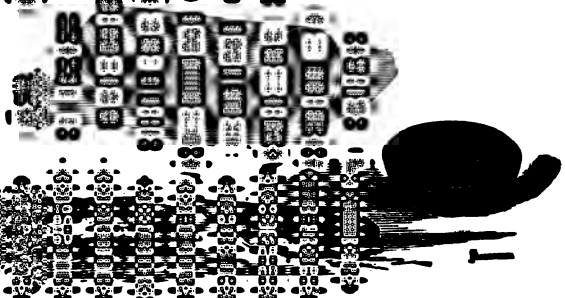
[illegible] nd 3ft. 2½in. diameter, [illegible] dy.

s.

nuing, the top opened
both back and front

plate, and so much
he ordinary working

none injured.



in. diameter, 60 lbs.
o that the longitudinal
of joint. A patch
and as the rivet holes
in caused by drifting,

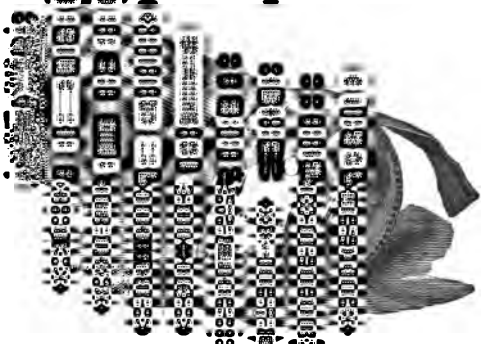
e, when two rings of
ms at each side until
at a distance of about
end was liberated and
wo pieces of the shell.
ack a few yards and
little injured.

over the fireplace, had
able to bear the very
air over the fireplace
and deposits of scurf
tact of the water with

1 *killed.*

some steam winches
e overheating of the
rom over pressure in

2 *killed*, 18 *injured.*



6in. diameter, tubes
ed with steam guage,
ve, loaded to 54 lbs.,
lbs., and had been at

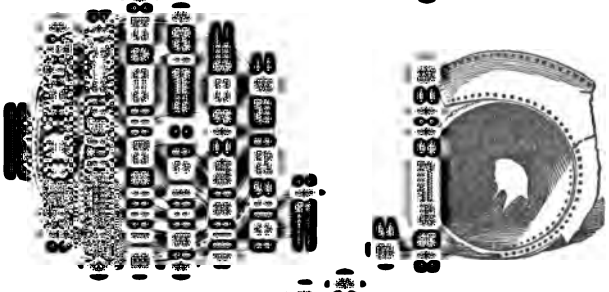
the shell were torn off
rtly round, and moved

er side of the back of
by the leaking of the

5 killed, 4 *injured.*

d 7ft. diameter, tube
es, 43 lbs., fitted with
mall for such a boiler,
ssure guage.

[illegible] front end was blown [illegible] and was driven against



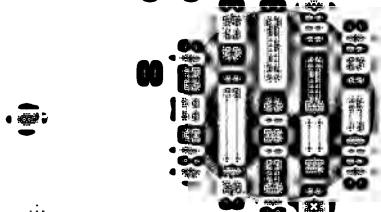
[illegible] main body of the shell, [illegible] within it, were driven [illegible] distance away. Very [illegible] property.

[illegible] ness of the tube of so [illegible], which made it unable [illegible]. It is very probable, [illegible] the pressure was con- [illegible] of the engine, and [illegible] tangled in the machinery.

1 *killed.*

[illegible] diameter, ⅝ inch plates [illegible] front part of the bottom [illegible] allowed the sides to [illegible] stroyed and torn into [illegible] be the defective state [illegible] longitudinally, were

none injured.



2 killed, 2 injured.

none injured.

ted, the bottom gave

made the boiler rise

tance away flattened

none injured.

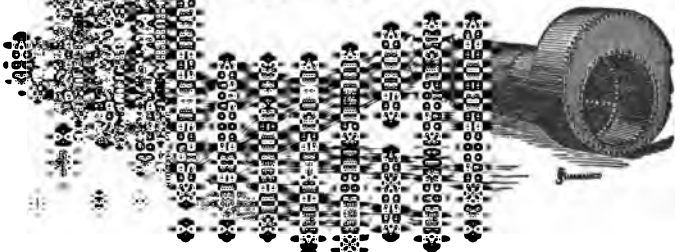


Fig. 6.

6in. diameter, taper

eter at back, $\frac{3}{8}$ inch

forming the bottom

guage, a pressure

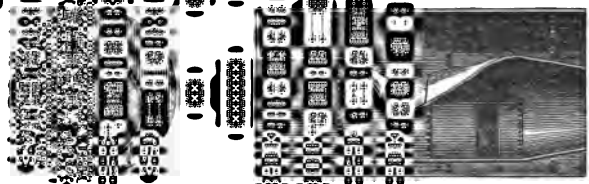
der side of the shell,

to open out by the

wn to a considerable

one ring of the shell
nd was thrown to the
away from the back.
sted on the side walls
boiler was thereby so
the ordinary working

1 *killed.*



diameter, taper tube,
r, and 2ft. diameter at
itted with glass water
safety valve loaded to

ing place in the second
caused the death of a
not injured or moved.
of water, and as the
in charge may have
ace, and the laminated
tube peculiarly liable

1 *killed.*

ameter, $\frac{3}{8}$ inch plates,
and 2 floats.
were thrown to a con-
en place immediately

[illegible] 1886.

[illegible] ting of the shell by [illegible] by the deposit from [illegible] of the water with

1 *killed.*

[illegible] eter, ⅜ inch plates, [illegible] boats, and two alarm

[illegible] e end was separated

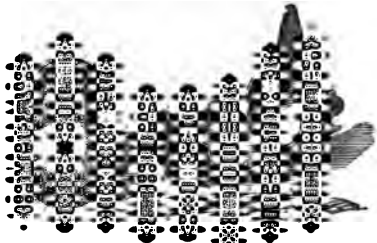
[illegible] g of the shell from [illegible] ssure, as the guage [illegible] the pressure had at

1 *killed*, 4 *injured.*

[illegible] diameter, tube, 4ft. [illegible]

[illegible] aining steam and water [illegible] o bear the ordinary

1 *killed*, 1 *injured.*



[illegible] d only 4ft. 2in. long, [illegible] as most inefficiently [illegible] diameter, and of such

under a pressure of
, and the guage cocks
ing water in the boiler
anhole was very large

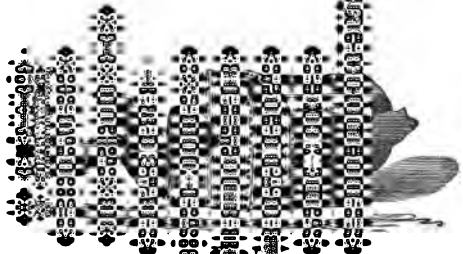
ntinued along the top
ongue-shaped strip of
ate; two strips about
The boiler had been
with the back about

y dry, and, during a
ation of steam caused

none injured.

f the vessel, and the
rge piece alighted on
ge.
d to be over-pressure

2 *injured.*



barrel of the boiler

was 6ft. 1in. long, 2ft. 5in. diameter the fire-box end was 3ft. wide, and 2ft. 4in. deep; the fire-box was 2ft. 5½in. wide, and 2ft. 7in. high, and 1ft. 9½in. deep, with 23 tubes passing from it through the barrel to the smoke box and chimney. The boiler was fitted with a 2in. safety valve, which was intended to blow at 45 lbs., but as there was no ferrule, it is supposed to have been screwed down to a much greater pressure.

The upper portion of the shell over the fire-box rent through the manhole, and allowed the shell to open out and fall on each side. A large portion of the front plate was also torn off.

The cause of the explosion was the weakness of the manhole, which was not strengthened by any ring, and also excessive pressure from want of proper safety valve.

No. 33. *Breage.* *June* 11*th.* 1 *killed.*

Cornish Boiler, 36ft. 6in. long, and 6ft. diameter, ⅜ inch plates, 45 lbs.

The tube collapsed and rent, and the issuing contents caused the death of the attendant.

The weak tube of such large diameter, was unable to bear the ordinary working pressure, having no strengthening rings.

No. 34. *Nottingham.* *June* 19*th.* 2 *killed,* 4 *injured.*

Locomotive, ½ inch plates, 140 lbs.

The explosion occurred at the left hand side of the ring of plates in the barrel next the fire-box, and below the foot-plate. The rent tore along the edge of the lap and into the next ring of plates. The reaction of the issuing contents threw the engine off the rails.

The cause of the explosion was partial corrosion at the point of rupture and strain of the plates, as the boiler itself formed part of the frame of the engine.

No. 35. *Richmond.* *June* 26*th.* 2 *injured.*

Locomotive, being tried for the first time. The funnel came in contact with a bridge, and the dome was also torn off.

No. 36. *Gainsbro'* *June 29th.* *none injured.*

No details have been obtained.

No. 37. *Durham.* *July 2nd.* 4 *killed.*

Plain Cylindrical Boiler, 30ft. long, and 6ft. diameter, $\frac{3}{8}$ inch plates, 28 lbs. It had been repaired a short time before the explosion, with 5 new plates.

The boiler was torn up into several pieces, but the main portion remained flattened out on the seating, while some smaller pieces were sent 250 yards away.

The cause of the explosion was the deterioration of the boiler, and its frequent repair over the fireplace.

No. 38. *Liverpool.* *June 12th.* 4 *injured.*

Elephant Boiler, 20ft. long, and 4ft. diameter, $\frac{3}{8}$ inch plates, and worked at low pressure. The bottom shell had a tube through its whole length.

A rent took place in the lower part of the fireplace, and extended along the bottom, and the reaction of the issuing contents caused the top to rear up.

The cause of the explosion was supposed to be that the bottom plates were worn too thin to bear the ordinary pressure.

No. 39. *Sheffield.* *July 4th.* *none injured.*

Two Tube Cornish Boiler, externally fired, 30ft. long, and 6ft. diameter, $\frac{3}{8}$ inch plates, 40 lbs.

The second seam over the fire gave way, and the plate sank down upon the fire.

The cause of the explosion was the deterioration of the seams over the fire, in consequence of the deposit of scurf which could not be properly cleared off owing to the internal tubes.

No. 40. *Oldham.* *July 14th.* *none injured.*

Boiler, with two internal furnaces, 9ft. 6in. long, and 2ft. 11in. diameter, $\frac{3}{8}$ inch plates, uniting into one tube beyond.

the boiler.

ve, and the steam

umulated than the

3 *injured.*

n. It was a plain

, and 7ft. diameter.

iler revolved, and

pressure of 30 lbs.,

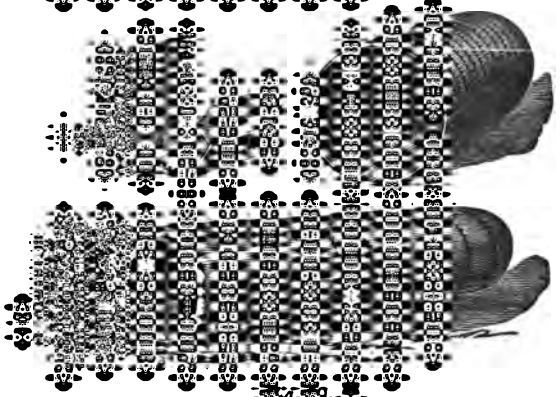
s a large manhole

lf was blown to

of the boiler was too

ng caused a central

2 *killed*, 7 *injured.*



$\frac{7}{8}$ inch plates, with

A tube 3ft. 3in.

front, and returned

1866.

and then passed to an

the hemispherical end.

way, and separated from

own to a good distance,

posite direction.

nstruction of the boiler,

here were no stays, and

e shell.

ed inside by two men,

losion.

2 *killed*, 6 *injured*.

23ft. long, 5ft. 3in.

e first ring of plates at

akness of the flat ends

1 *killed*, 3 *injured*.

iameter, with 140 2-in.

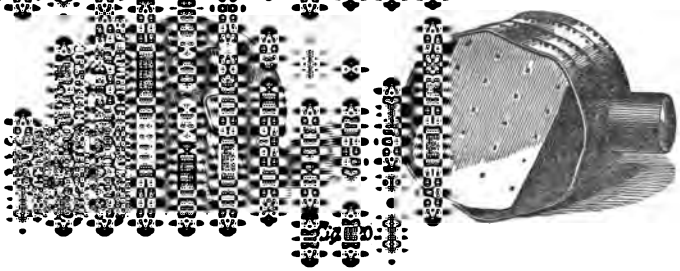
3in. broad, and 5ft. deep,

It was fitted with two

of the left side, 2ft. 6in.

h, and the issuing water

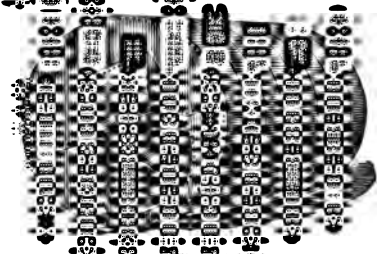
3 *killed*, 5 *injured*.



6in. diameter, with an internal chamber box and chimney in t.

, and was blown r portion remaining the water, and the to be thrown on to

1 *injured.*



diameter, taper tube nd 2ft. 6in. diameter

ce gave way on left were forced out of

3 *killed,* 1 *injured.*

been tested to 60 lbs.

ck, and the issuing

ted by testing.

2 *killed,* 2 *injured.*

ppage from accumu-

3 *killed*, 6 *injured*.

meter, $\frac{7}{16}$ inch plates,

ater, and the main bulk

e air to a great height,

2 *killed*, 30 *injured*.

Fig. 22.

diameter, with tubes,

shell, allowing the portion containing to the right. The ubes and back end, . The tubes were some large coping ces were uninjured, verheating.
hell, where it rested that it was unable
show their position

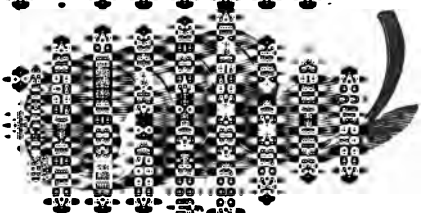
none injured.

shortness of water, the door frame.

1 *injured.*

meter, ⅜ inch plates,
that the bearing of plates was torn
t.
plates rested against the bear the ordinary

7 killed.



meter, tube 2ft. 6in.

diameter, $\frac{3}{8}$ inch plates, 100 lbs. It was double-rivetted, and the crown of tube was strengthened with angle iron. The shell was formed of six rings, each of two plates alternately jointed top and sides. The third ring from the front had stripped off, and was thrown to the right and forwards against a wall. The line of rent was confined to the plates forming the ring, which was an outer one, and covered the two adjoining rings in the laps, the rent being from the edge of the inner lap to the nearest rivets. The first rent had taken place in the solid iron, about 1 inch from the rivets of a seam on one side, and from this the rent had extended along the seams on either side, and of course the whole ring soon tore off when the equilibrium was destroyed by the first rent.

The fittings of the boiler were sufficient, except that there was only one safety valve, and that was so constructed that it could only open a very little way.

The cause was a defect in the iron at the point of the first rent, and accumulated pressure during the time of standing.

No. 54. *Macclesfield.* *September 25th.* *none injured.*

Multitubular Boiler, with large internal fireplace, 60 lbs.

The furnace crown became overheated from shortness of water, and was crushed down and torn across two seams. The boiler was lifted from its seat and thrown back against a stone wall.

No. 55. *Chelmsford.* *October 5th.* 1 *killed*, 7 *injured.*

Agricultural, 45 lbs., and had only just been set to work.

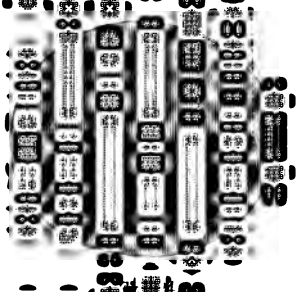
The crown plate to the fire-box was so deeply corroded from long wear that it gave way, and the issuing contents scalded those near.

No. 56. *Greenwich.* (*Fig.* 24.) *October 8th.* 2 *killed*, 2 *injured.*

Marine, 16ft. long, slightly oval, front end flat, 8ft. 6in. wide, 7ft. 10in. high, and the dimensions of the back hemispherical end were 2ft. less each way, $\frac{3}{8}$ inch plates, 26 lbs. There were two internal fireplaces, of irregular shape, uniting at the back into one flue of similar shape, which did not come to the front, but passed through the steam space, and out at the top of the boiler.

steam up, the wing

wing side, as shown



water to escape into

ent along the edge of

htly nicked in the

from the front, and

vets from the crown

ss seam the furnace

side of the furnace,

d. There was also a

shell, as shown in

s of the shape of the

d evidently gradually

sion, and eventually

mptoms of the same

sponding flue of the

7 killed, 1 injured.

meter, with internal

chimney at the top,

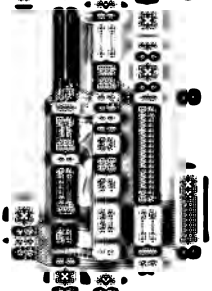
many pieces, leaving

e of the rents showed

unstrengthened by a

fractures had led away

fact, that the manlid



ugh to make its way

front plate divided into

hile the back plate was

ion to the manhole.

ion of overheating, but

ion passed through the

the action of the fire,

water. The manhole

plate, and held in by

when carelessly screwed

ine was standing after

alve was very defective,

gainst almost any pressure,

ated much higher than

nd led to the sudden

ings, rendered it unable

safety valve ought to

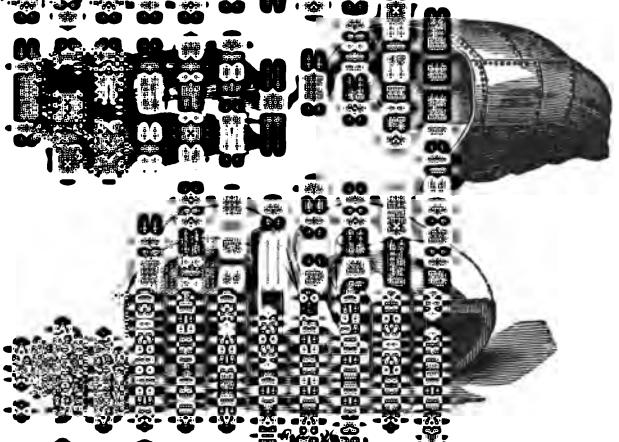
1 *killed.*

, internal flue 3ft. 3in.,

on three saddles, with

ottom of the boiler,
he issuing contents

7 killed.



They were 16ft.
and somewhat less at
internal fireplaces,
front and passed up
shell into the funnel.
the outside fireplaces
but the weakness of
stays between the
ountings to the boiler

corroded that they
allowing the sides
Each shell fell at
arts of the front ends
of the side flues that
Small pieces of the
the sides of the vessel

1866.

leakage of the vessel,
et.

none injured.

and 2ft. 6in. diameter,
heat passed through a
box and chimney.
box end was torn from
fragments that could be
over. Part of the fire-box
the boiler was travelling,
in it, first struck a rail
n rebounded to a point

vered from the river to
resumed that, although
sure was shown by the
pressure must have risen
, and to more than the

none injured.

ameter, tube 4ft. 6in.
an unusually large dome
le of the shell was cut
was peculiarly weak.

was being got up

ure was caused by

pt have been very

ked in the sketch,

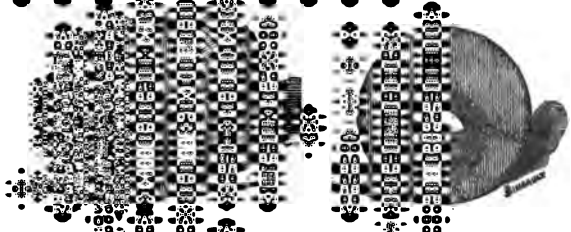
the juncture of the

ch side of it, and so

atents of the boiler

the boiler on its seat.

1 *killed*, 1 *injured*.



VIEW.

8in. diameter, tube

over-pressure, as the

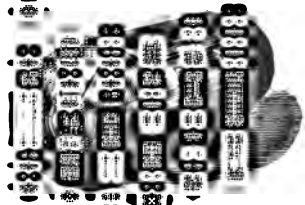
r of the safety valve

ssion that he could

night, to be available

1866.

th, *none injured.*



ng, and 5ft. diameter,

ling and emptying, and

e edges, and measured

nd the lid fitted on the

crack shown in sketch,

commencement of the

vented from leaking by

rength.

lving, the manlid was

y through the floor, and

the manhole, and blown

he strength on one side,

atrived to compensate at

strain when revolving,

es together were sufficient

rking pressure of 12 lbs.,

en increased to 35 lbs.,

ying the steam, although

e.

s year) clearly show that

e fire, or any chance of

se very great destruction,

of pressure which is so

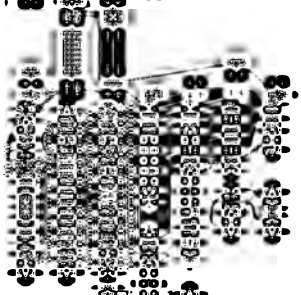
the havoc caused by

none injured.

of $\frac{7}{16}$ inch plates,
nal fireplaces united

junction of furnaces
ak shape as to be

3 *killed*, 2 *injured*.



meter, $\frac{1}{4}$ inch plates,
ad. Two $11\frac{1}{2}$-inch
nd of the boiler, and
nal smoke box and

was forced upwards,
ox.
of patches, that they
ssure during a short

2 *killed*, 6 *injured*.

in. diameter, tubes
he approved manner.
was ruptured at the
ne of rivets on each

1866.

and turned completely
hat it was before.
he seams beneath the
cause of explosion.

none injured.

ns, 9ft. long, 3ft. 3in.

nd the reaction of the
yards away, and one of
flew to a considerable

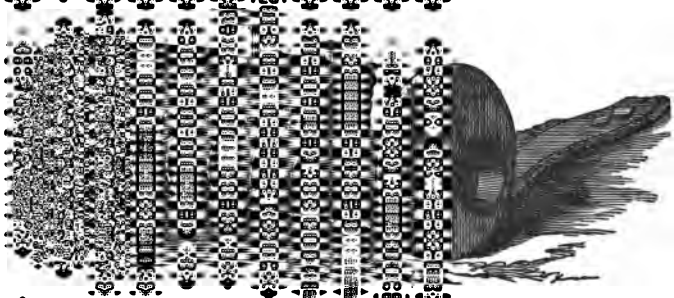
that they gave way on
temporary stoppage of

1 *killed*, 1 *injured.*

pherical ends, and 7ft.

essure and thinness of

5th. *5 injured.*



diameter, tubes 2ft. 8in.
r was fired in each of
heat from two furnaces
outside shell.

Both the internal furnaces collapsed, until the crowns almost touched the fire bars, as shown in dotted lines, but without fracture. The back of the shell, on the right side, had evidently been overheated, and had rent along the centre of a bulge, and this rent had extended along the line of rivets of the transverse seam on each side, allowing two rings of the plates of the shell to open out flat as shown. There was a bulge on the plate, on the right side of shell, corresponding with the one which parted on the opposite side.

The cause of the explosion was overheating of the plates from shortness of water.

No. 70. *Aberdeen.* *December 24th.* 1 *injured.*

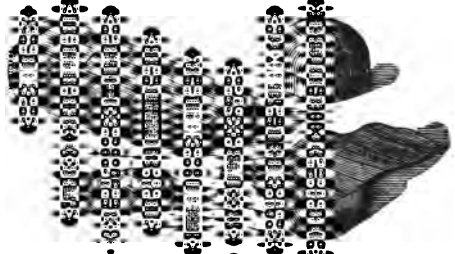
No particulars have been obtained.

[illegible] IN 1867.

1 *killed*, 1 *injured.*

[illegible] d, causing great damage, [illegible]. All such boilers should [illegible]

3 *killed*, 3 *injured.*



[illegible] 33 lbs. pressure. Only [illegible] and had worked before at [illegible] d, and old fitting-holes [illegible] a seam at front end, over [illegible] on back, and front end [illegible] e of explosion was, that [illegible] red, and also incautious [illegible]

No. 3. *Sheffield.* (*Fig.* 2.) *January 2nd.* 1 *killed*, 4 *injured.*

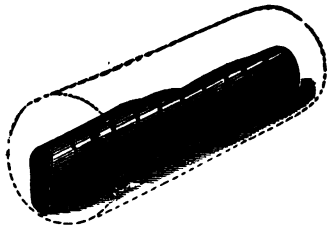


Fig. 2.

One Tube externally fired, 30ft. long, 6ft. 6in. diameter, with dished ends. Tube 2ft. 9in. diameter, slightly oval. Pressure 60 lbs. Tube collapsed sideways from end to end, because it was not strengthened by hoops or other means, which were the more needed, because it was slightly oval, and the longitudinal seams were nearly in one line.

No. 4. *Preston.* *January 3rd.* 1 *killed.*

Boiler for heating apparatus. Fire was lighted without noticing that as there was no safety valve, and that all escape of steam was prevented by the connecting pipes being frozen.

No. 5. *Westerham.* *January 5th.* 1 *killed.*

Cast-iron Boiler for heating water for a horse shower bath, fixed behind an ordinary fireplace. Burst and caused great damage, owing to the pipes being frozen. There was no safety valve.

No. 6. *Barr.* *January 9th.* 1 *killed*, 3 *injured.*

Kitchen Boiler, which burst because the supply pipes were stopped by frost, and there was no safety valve.

No. 7. *London.* *January 11th.* 1 *killed.*

Cornish, 12ft. long, 4ft. 6in. diameter, tube 2ft. 4in. diameter, pressure 40 lbs. Small piece of plate was blown out near the bottom, and the boiler was displaced by the reaction of issuing

1867.

sive external corrosion

none injured.

age, because pipes were

as no safety valve.

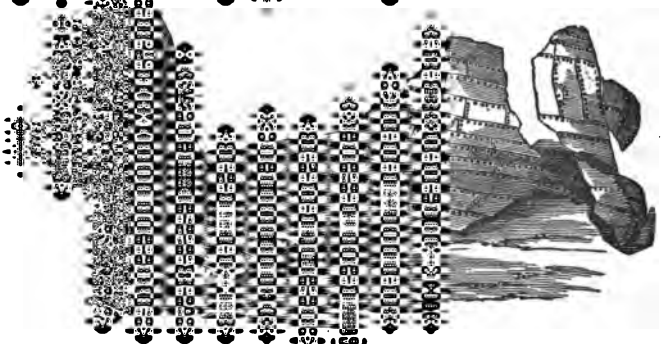
1 *killed.*

e days, and the boiler

h damage, because the

ere was no safety valve

3 *injured.*



meter. Pressure 30 to

attened out and scattered

tch so as to show their

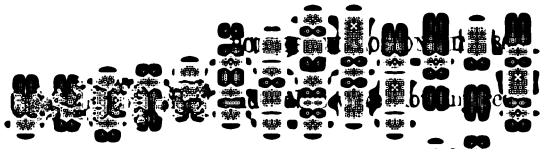
ed a very long time, and

red line.

2 *killed*, 2 *injured.*

ubes 1ft. 10in. diameter,

wing boiler upwards by



The flat end was

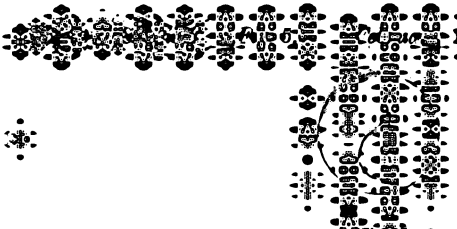
to the centre, the

1 *killed*, 4 *injured.*

ve way at centre of

d it was suspected

4 *injured.*



ed. Tube collapsed

ithout injuring front

er, but most likely

none injured.

ightly oval; plates

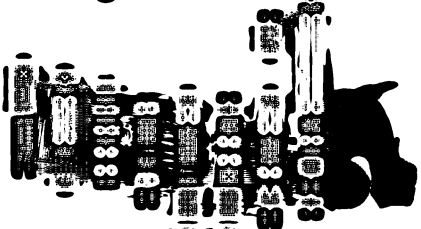
s. Shell had once

which were in one

[illegible] 1867.

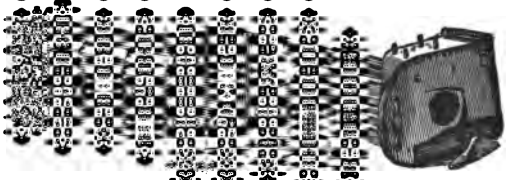
[illegible] away, leaving tubes [illegible] tive form and worn out

1 *killed*, 3 *injured*.



[illegible] blew off, and the outer [illegible] osion was over-pressure

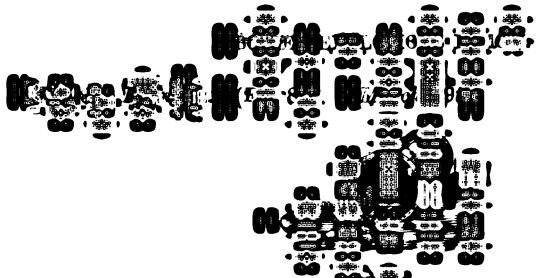
8 *killed*, 4 *injured*.



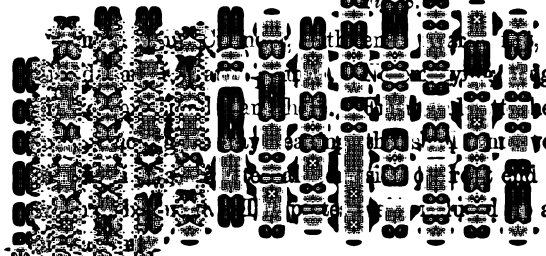
[illegible] and tubes blew out. [illegible] the safety valve was

3 *killed*, 1 *injured*

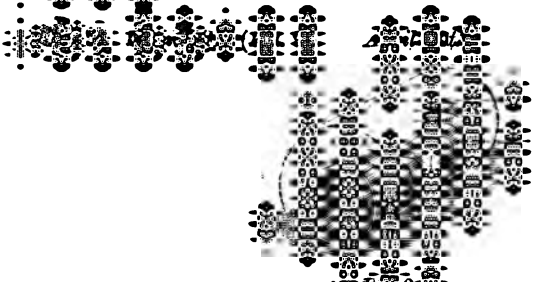
[illegible] two while the engine



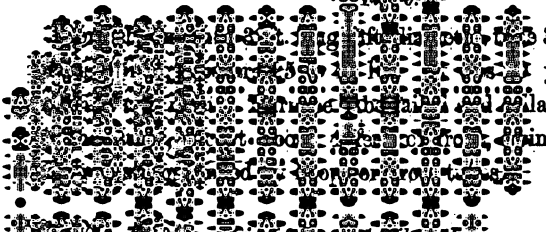
2 *killed*, 2 *injured.*



4ft. 7in. long, 2ft. g or feed-pipe, and ed by slight angle ved. The cause of and owing to very bad a knife edge in line

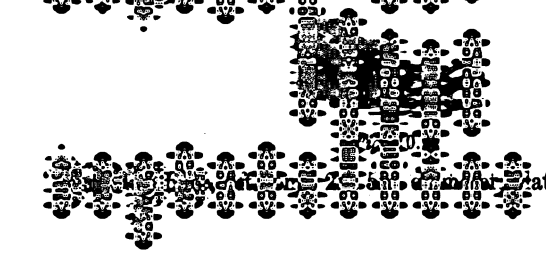


1 *killed*, 1 *injured.*



3ft. 10in. diameter, years old, but just lapsed from one end ing to its weakness,

1 *killed*, 2 *injured.*



ates ¼ inch, pressure

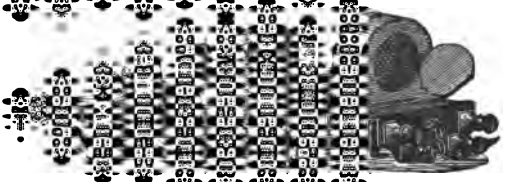
1867.

pressure, as the escape
g in the exit pipe.

2 *injured.*

ameter, plates $\frac{5}{16}$ inch,
ial very inferior. Piece
ved manlid to blow out
plosion was, the large
alve was too small, and

1 *killed*, 1 *injured.*



own away and broken to
cause of explosion was
sed by its being made a
expansion, and thereby

4 *injured.*

diameter, tube 3ft.
nds came out and
being broken. The
kmanship, and tube

2 killed.

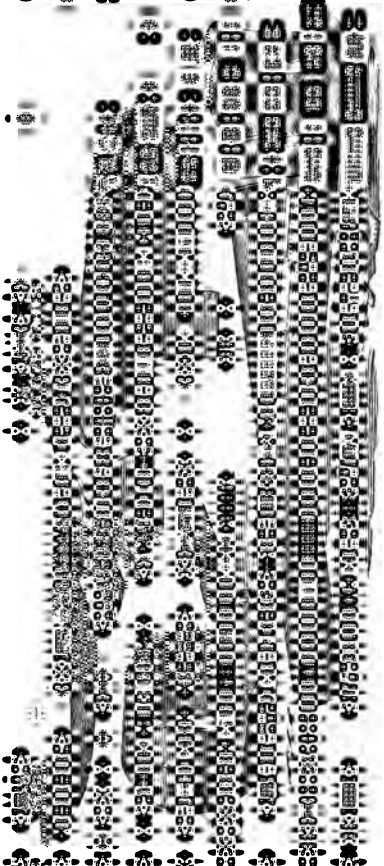


Fig. 14.

diameter, tubes 2ft. 4in.
put in bottom gave
out, dividing into

1867.

…eat distances, but are …al position. The cause …fireplace, and external

1 *killed*, 2 *injured.*

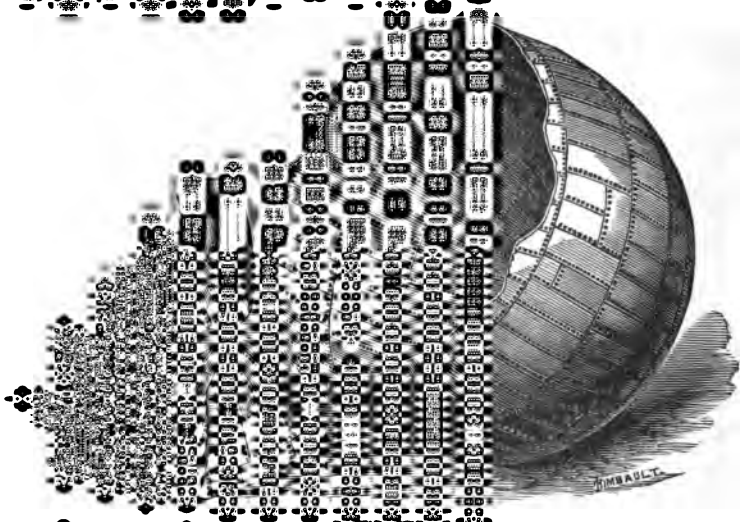


Fig. 5.

… Bottom blew out and … fell over on to another … rrosion along the bottom

3 *killed*, 3 *injured.*

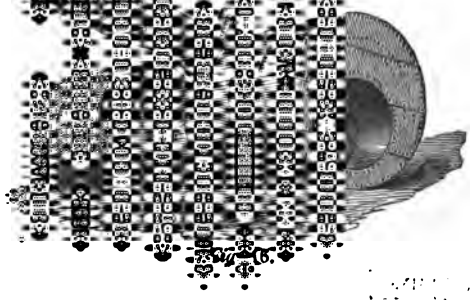
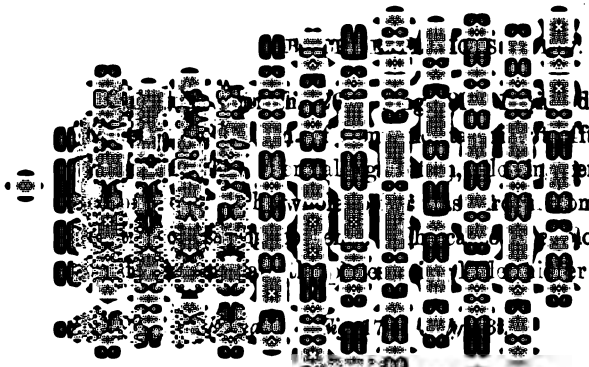


Fig. 6.



diameter, tube 5ft.
ft. diameter at back,
entral ring of plates
me distance by the
losion was corrosion
r than paper.

none injured.

be 2ft. 7in., tapering
osed, and about the
from seam to seam.
ause the water was

1 *injured.*

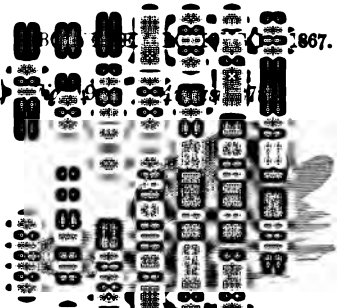
of high top fire-box
kely the boiler being
for expansion.

1 *killed*, 2 *injured.*

steam and hot water
boiler through the

867.

7 *killed*, 3 *injured*.



tube 1ft. 6in. diameter, no stays. End plate nt in back angle iron. and want of stays, and

2 *injured*.

none injured.

mouth-piece of man- allowed lid and upper

4 *injured*.

pipes placed in the flue. ing boilers to be unseated. of the explosion.

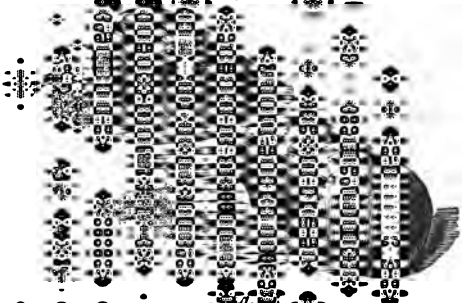
1 *killed*.

plates ⅜ inch, tube
underneath. Top
to the front. The
the bottom where

none injured.

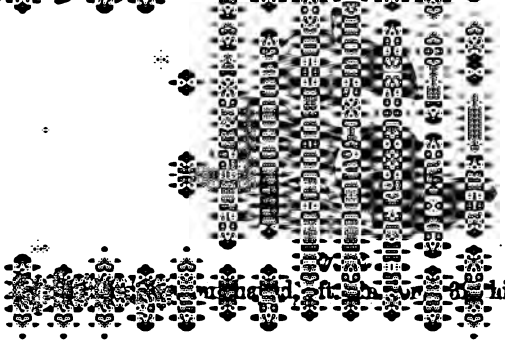
ft. 11in. diameter,
for want of proper
nd throwing boiler

1 *killed*, 1 *injured.*



re 40 lbs. It was
ch patched. The
boiler.

2 *killed*, 3 *injured.*



high, 2ft. 4in. wide,

1867.

tion of barrel blew off.

sure from locked safety

1 *injured.*

lin. diameter, pressure

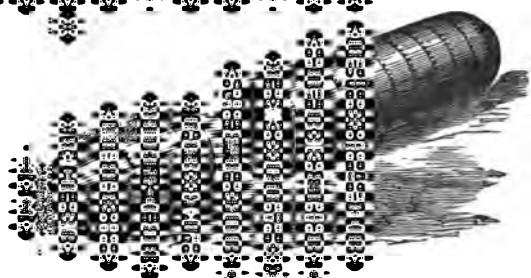
in portion thrown back

e root of angle iron, and

cause of explosion was

bad safety valve, which

11*th.* 3 *killed,* 10 *injured.*



plates $\frac{7}{16}$ inch, pressure

nt thrown forward and

losion was a seam-rip of

ture.

th. 4 *killed,* 3 *injured.*

iameter, plates $\frac{7}{16}$ inch,

ubes and taper junction

shell not injured.

tom part of taper

ire tubes, collapsed

of proper stays or

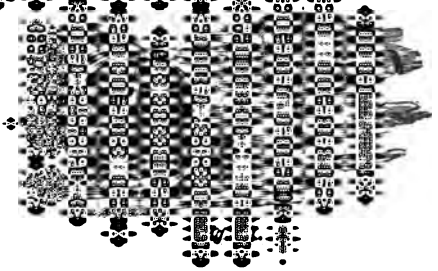
There was only one

3 *killed*, 2 *injured*.

sure 44 lbs. Tube

late and partially

1 *killed*.



1867.

plates $\frac{7}{16}$ inch, pressure
ube had been taken out,
t. Main shell thrown
kness of construction in
to compensate for loss

none injured.

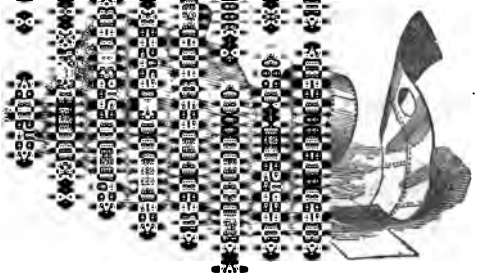
Fig. 23.

eter, tube 4ft. diameter,
collapsed for the whole
ined.

2 *killed.*

nd a blank flange used to
thout shutting the stop-
blew out when the bolts

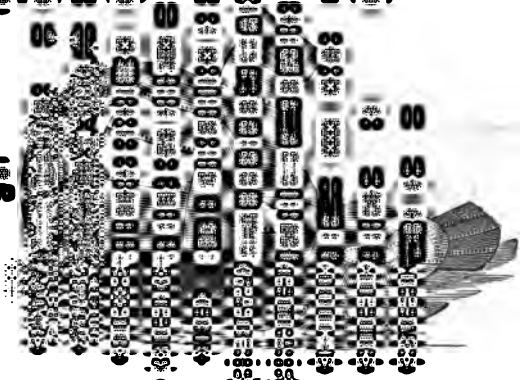
23*rd.* 6 *killed,* 4 *injured.*



er, tube 3ft. 2in. diameter,
ng bottom, and two rings

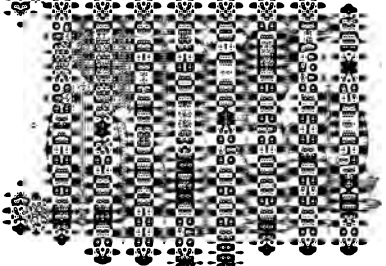
[illegible] ach injured. The [illegible] part resting on

1 *killed.*



[illegible] ough, plates ⅜ inch. [illegible] ssure 8 lbs. Boiler [illegible] safety valve loaded [illegible] pressure for an old

2 *injured.*



[illegible] ter, tubes 2ft. 7in. [illegible] r, and shell blown [illegible] ed. The cause of

[illegible] 1867.

[illegible] to a knife edge all along

[illegible] 2 *killed*, 1 *injured*.

[illegible] diameter, plates $\frac{3}{8}$ inch, [illegible] a new plate had lately [illegible] and rent, and back end [illegible] plosion was deterioration

[illegible], 1868.

none injured.

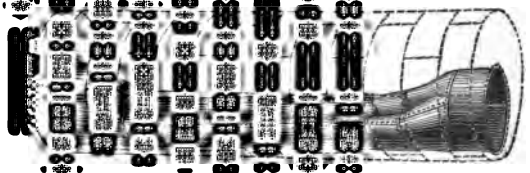
[illegible] ft. diameter, $\frac{8}{8}$ inch [illegible] torn up, and all the [illegible] position. The cause [illegible] very old and much [illegible] ordinary pressure. [illegible] the entrance of the [illegible] to the weakness.

1 killed, 5 injured.

[illegible] used for generating [illegible] ter, $\frac{7}{16}$ inch plates, [illegible] n, owing to inferior

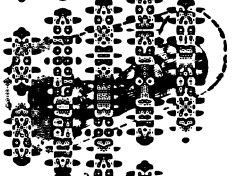
…PRESSION 1868.

1 *killed.*



…long, 6ft. 6in. diameter. …lbs. pressure. The dotted …be collapsed from end to …ng to the weakness of so …

1 *killed.*



…10in. diameter, ⅜ inch …In sketch the external …be to be seen. The tube …rent open at one seam, …although the boiler itself …

1 *injured.*

…view of fire-box with

box burst inwards

corroded to less

none injured.

external fire grates

ft. 2in. long, 6ft.

40 lbs. pressure.

of the tubes being

ther higher in the

me overheated from

tle disturbed.

none injured.

ter. Tube 2ft. 3in.

lbs pressure. The boiler rent open at

ace by the reaction

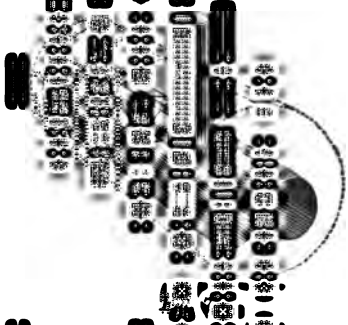
ottom were reduced

brickwork, so that

pressure.

1868.

2 killed, 1 injured.



n dotted lines in sketch,

0ft. long, 7ft. diameter,

grates in the flues were

ack with a central return

of the boiler. The sides

packed closer together,

ich was flattened on both

e left side collapsed and

ue, blowing out the grate

none injured.

long, 3ft. 11in. diameter,

end gave way at the root

wn 60 yards to the rear.

up by the reaction of the

l. The cause of explosion

end.

1 *killed*, 4 *injured*.

diameter, ⅜ inch
rn and scattered,
nproperly arranged
lately put on, and
wear, that it was

1 *killed*.

iculars have been
lown out and did
nt of proper stays.

1 *injured*.

4ft. 7in. diameter.
essure. The tube
its weakness with

1 *killed*.

be collapsed, owing

none injured.

34ft. long. Tube
be collapsed owing

1 *killed*, 1 *injured.*

long, 1ft. 8in. diameter, at a faulty place at the le, allowing the hot water urbed.

1 *killed.*

ith small return tube, 7ft. s, tube 2ft. 7in. diameter, apsed and rent open owing ndition, and the contents age to the boat.

2 *killed*, 2 *injured.*

long, 3ft. diameter, ¼ inch ond-hand boiler, and rent work, owing to its having

1 *injured.*

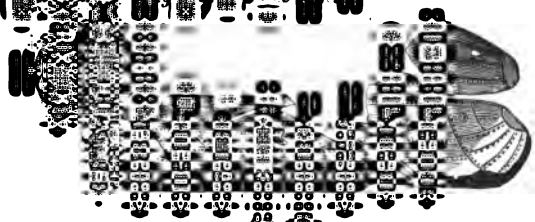
ft. diameter, ⅜ inch plates, t and caused considerable ae distance. The end was

2 *killed.*

7ft. 2in. diameter, $\frac{5}{16}$ inch two internal furnace tubes

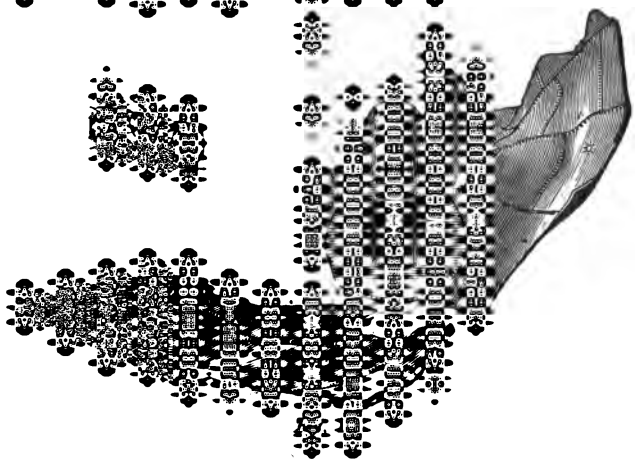
the front by four
lingly weak shape
were not attached
collapsed upwards,
o violently escape.
ure than usual at
nsafe, even at the

2 *killed.*



diameter, ⅜ inch
ed longitudinally.
torn into 4 pieces,

1 *killed,* 6 *injured.*



1868.

iameter. Tube 3ft. 3in.
The seams were arranged
the seams, but had torn
extensive corrosion had
nd all the shell was blown
end for end.

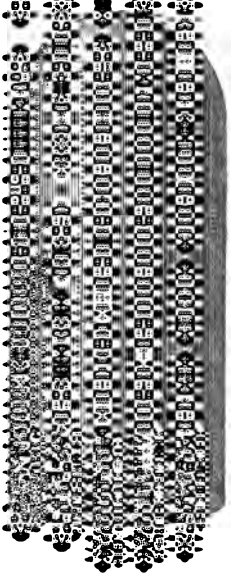
none injured.

in. diameter. Tube 3ft.
Left hand tube collapsed
thout strengthening rings.

6 *injured.*

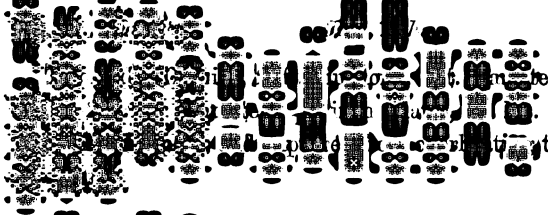
diameter. Tube 2ft. 3in.
e. The shell was blown
intact. The bottom was
gth of the boiler was so
pressure.

2 *injured.*



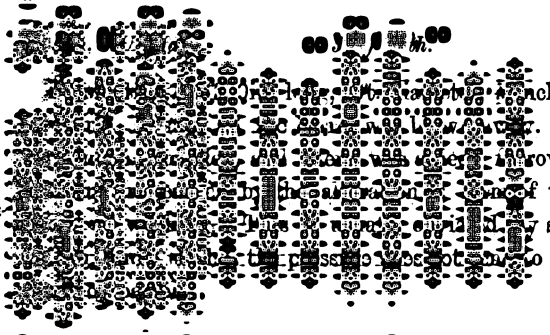
diameter, ⅜ inch
out of the bottom,
surrounding the
e in the line of
pe joint.

1 *killed*, 1 *injured*.



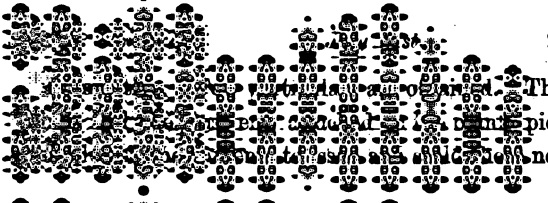
ber, ⅜ inch plates.
pressure. Both
through shortness

3 *injured*.



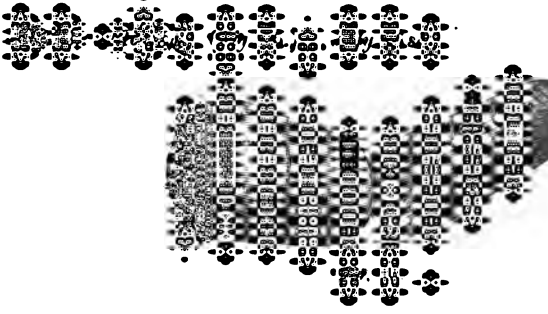
nch plates, 130 lbs.
The inside was
row at the line of
of the boiler in the
substituting butt
o alter the circular

2 *killed*, 1 *injured*.



The connecting rod
pierced the boiler,
near.

1 *killed*.



1868.

in. long, 5ft. diameter,

er parted at a seam over

rown upwards and to a

ck part of the boiler was

place at a seam-rip at the

while the fire was being

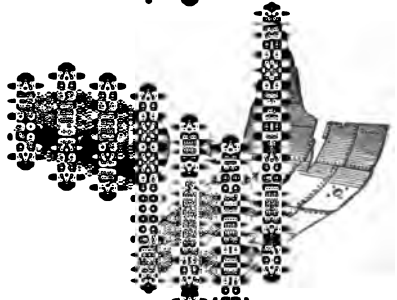
2 *killed*, 3 *injured*.

lling, by its own steam

ra pressure of steam was

was torn in pieces, and

1 *killed*.



ng, 5ft. diameter, $\frac{3}{8}$ inch

e way on the side where

being too low, and the

nd thrown some distance

by its remaining attached

while the front end was

was thrown also to the

eam.

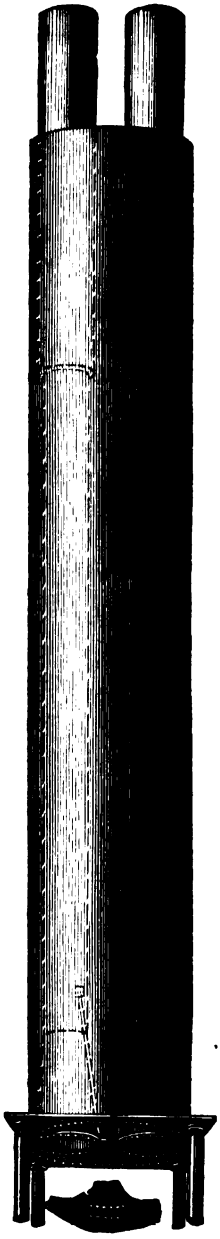


Fig. 17.

No. 31. *Liverpool.* (*Fig.* 17.) *August* 20*th.* 7 *killed,* 5 *injured.*

Two Furnace Chimney Boiler, 42ft. 4in. high, 6ft. 9in. diameter, ½ inch plates, 50 lbs. pressure. Nearly half the bottom plate was blown out, and the issuing contents found their way into the furnace and increased the damage. The line of rupture near where it joined the shell was corroded almost to a knife edge, which so reduced its strength as to make it unable to bear the usual working pressure of steam, in addition to that of the column of water in the boiler.

No. 32. *Accrington. August* 31*st.* 1 *killed.*

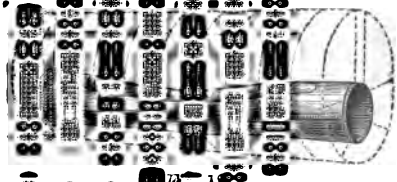
A Kier or Steam Bleaching Chamber, somewhat like No. 2, and not used for generating steam, 9ft. high, 8ft. diameter, ½ inch plates, 50 lbs. pressure. The bottom blew out, and the shell was torn to pieces. The cause of explosion was weakness of the ruptured end, and want of care in working.

No. 33. *Birmingham. September* 11*th.* 1 *killed,* 1 *injured.*

Two tube Cornish. The manlid was wrongly fixed outside with internal clamps. It was being screwed up tighter to stop leaking when the bolt broke, and the lid came off and allowed the contents of the boiler to escape.

1868.

21*st*. *none injured.*



18ft. 6in. long, 6ft. 6in.

es, 40 lbs. pressure. In

o allow the tube to be

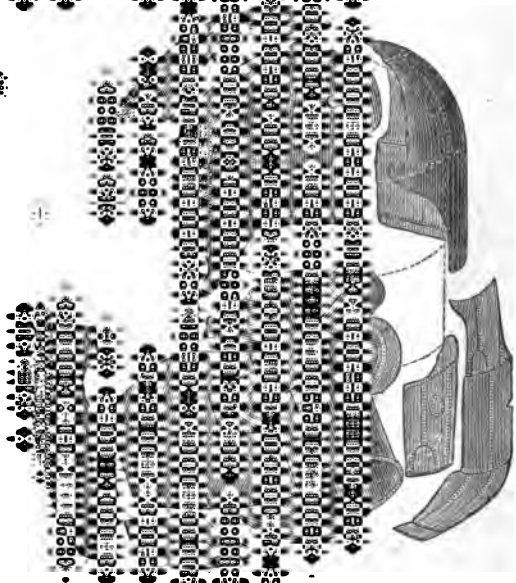
d and ruptured at two

y as to knock down the

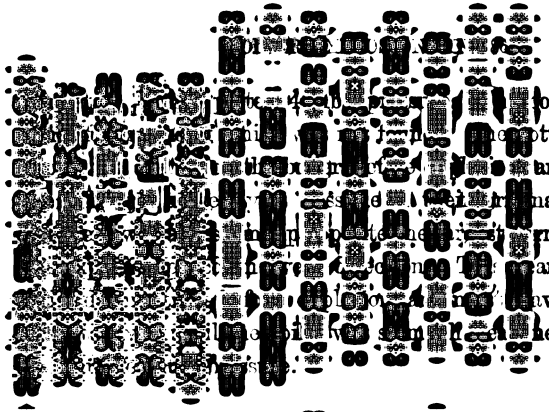
ube was in a very weak

bear the usual working

13 *killed*, 2 *injured*.



22ft. high, 10ft. 6in.

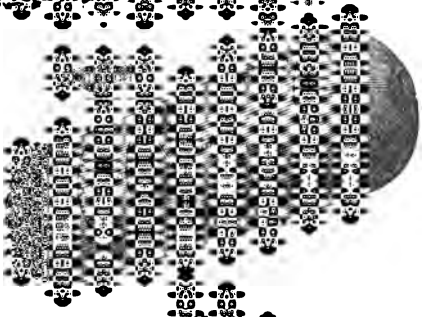


oiler was rent into
otted line in sketch
and the fragments
nal position. The
nace, from whence
am-rip must have
ve extended from
ed as to be unable

1 *killed.*

The end over the
A thick accumu-
e plate to become
water.

2 *killed.*



high, 7ft. diameter,
of plate was blown
the issuing contents
was said to be over-
centre tubes were
overheated from the
rapid a generation

No. 38. *Glasgow.* *October* 12*th.* 1 *killed*, 1 *injured.*

Plain Cylinder, 39ft. long, 5ft. diameter, $\frac{3}{8}$ inch plates. A small piece of plate about one-and-half-feet area blew out of the bottom, and the contents issued so violently as to do much damage, although the boiler itself was not otherwise injured. The ruptured plate was corroded to $\frac{1}{16}$ inch thickness by the leaking of seams, caused by the feed water entering close to the bottom of the boiler.

No. 39. *Swansea.* *October* 13*th.* 2 *killed*, 1 *injured.*

One of twenty-four. One tube Cornish, worked by two furnaces, 23ft. long, 6ft. 6in. diameter. Tube 3ft. 9in. diameter, $\frac{1}{2}$ inch plates, 40 lbs. pressure. The tube was divided by a wall down the middle. The tube collapsed sideways. It was said that one side was overheated through shortness of water, but it is more than probable the explosion was owing to the weakness of so large a tube without strengthening rings.

No. 40. *Preston.* *October* 16*th.* 2 *injured.*

This was an arrangement of pipes, called an "Economiser," placed in the flues of a set of boilers for heating the feed water. It was shattered into fragments, causing considerable damage. As the whole apparatus was said to be in proper order, the explosion had been attributed to coal gas in the flues, and some peculiarities in the ruptured pipes bear out the supposition.

No. 41. *London.* (*Fig.* 21.) *October* 19*th.* 6 *injured.*

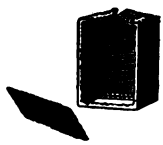
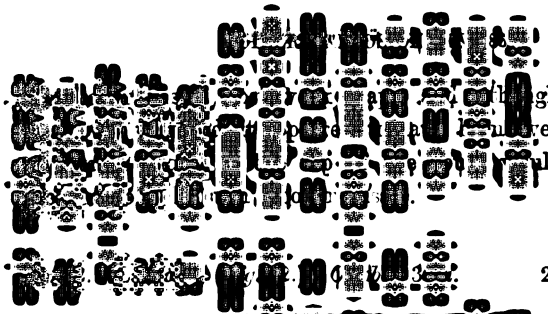


Fig. 21.

Kitchen Boiler, for supplying hot water to the top of a lofty house. It was rectangular, 3ft. 6in. wide, 2ft. 6in. high, and 1ft. deep. The front was blown out and caused considerable damage.

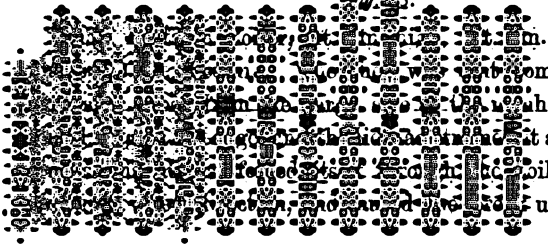


gh no pressure of
erlooked that the
ld give sufficient

2 *killed*, 10 *injured*.

inch plates, 50 lbs.
de, 2ft. 6in. high.
er at back end. In
to allow tube to be
fire bars, and rent
t open at each side,
of the tube was of
the collapse of the

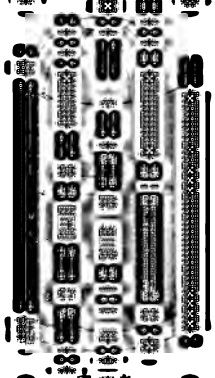
1 *injured*.



m. diameter, ¼ inch
ompletely off. The
hole, which had no
t and caused several
oiler, and the rents
up of the boiler.

1868.

3 *killed*, 3 *injured*.



diameter, ½ inch plates.
ter at bottom, 5ft. 3in.
pressure. In the sketch
ne internal fire-box to be
ces, many of which were
ion as to the cause of the
s not very firmly stayed,
by corrosion round the

1 *injured*.

at the back. The back
ly corroded, and allowed

e given which are not
e list.

none injured.

long, 5ft. 6in. diameter,

allowed to get low,

the steam to escape

none injured.

high, 9ft. diameter,

as allowed to get so

he side tube slightly

the feed water had

aces without causing

had been put into a

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